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REMOTE SENSING AND THE PRIVATE SECTOR

ISSUES FOR DISCUSSION

A TECHNICAL MEMORANDUM

MARCH 1984

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Preface

In March 1983, the administration proposed to transfer the meteorological and land remote-sensing (Landsat) satellite systems to private ownership. This proposal has raised a variety of issues, including concern over the small size of the market for remote-sensing data, the public good aspects of remote sensing, and use of the data to further foreign policy objectives.

In November 1983, Congress resolved one of the issues by deciding that the meteorological remote-sensing systems should not be privately owned; the Government will continue to operate them in the public interest. However, the Landsat system is still under active consideration by the Congress for transfer to private ownership, and Congress is now considering legislation designed to make such a transfer as smooth as possible.

U.S. systems have demonstrated to a variety of users, in the United States and abroad, that land remote sensing from space can be a powerful tool for mapping, assessing, and managing land resources. It may eventually be possible to establish a self-sustaining business selling data from a privately owned and operated land remote-sensing system to Government, private, and foreign customers. However, as the debate over whether and how to transfer the Landsat system has shown, the process of transferring Government-developed technological systems to the private sector is difficult and involves a wide variety of agencies and institutions, each with a different view of the appropriate means of transfer.

This technical memorandum, which was requested by the House Science and Technology Committee and the House Government Operations Committee, is designed to help Congress determine the appropriate requirements and conditions for private sector ownership of the U.S. land remote-sensing system. It also provides information and analysis that will be useful for Congress as it considers transfer legislation. This technical memorandum constitutes a portion of a major assessment of international cooperation and competition in civilian space activities that was requested by the House Science and Technology Committee and the Joint Economic Committee.

In undertaking this study, OTA sought the contributions of several Government agencies and a wide spectrum of knowledgeable and interested individuals. More than 50 persons contributed to this technical memorandum, either to provide data or to review early drafts. OTA gratefully acknowledges their help. We are particularly grateful to our workshop participants. Finally, OTA appreciates the assistance it received from the Congressional Research Service, the Department of Commerce, the Department of Defense, the Department of State, the Central Intelligence Agency, and especially from the National Aeronautics and Space Administration, and the National Oceanic and Atmospheric Administration.

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Chapter 1

Executive Summary

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Chapter 1

Executive Summary

A process is now under way that is intended to lead to the early transfer from the Federal Government to the private sector of the Land Remote Sensing Satellite (Landsat) system for remote sensing from space. This technical memorandum was prepared at the request of the House Committee on Science and Technology and the House Committee on Government Operations, which are overseeing this process. The House Committee on Science and Technology is also simultaneously preparing implementing legislation.

This process inevitably raises the separable issues of **whether** to carry out the transfer at all, or **how** to carry it out if the Government does go ahead. This memorandum only indirectly addresses the question of whether the transfer is in the net public interest by focusing on **one aspect** of such a transfer: it discusses the various **public benefits** provided by the Government's civilian meteorological and land remote-sensing systems and analyzes the effects that transfer of these systems to the private sector might have on the provision of these public benefits.

Principal reasons for transferring remote-sensing services to private hands are that the private sector excels both at innovation and at developing markets. In an earlier study, OTA found a potential exists for greatly expanding the market for land remote-sensing services, and that other nations intend to compete for the market.[1]

Another reason for transferring these services to the private sector is the hope of reducing Federal expenditures. This technical memorandum bears directly on the question. Most of the public benefits which the United States now derives from remote sensing could be provided just as well by the private sector—for a price. However, OTA has found that a private owner/operator who was obliged by contract to provide all of these public benefits would probably require a large Federal subsidy. **Until the market expands substantially, and more efficient spacecraft are developed and deployed, it could cost the Federal Government as much to subsidize a private owner as to continue operating the system itself.**

The public benefits of land remote sensing *could* justify any of the following policy options:

- continued Government ownership and direction of the system, whether or not actual operation was contracted out; *or*
- maintenance of Government ownership for a limited period, in order to effect a phased transfer to the private sector, as the market grows large enough to support commercial ownership; *or*
- mixed, public-private ownership of the system; *or*
- quick transfer to a private owner/operator, but with a series of conditions and requirements designed to assure the public benefits; *and*
- a substantial subsidy to a private owner, in order to maintain the public benefits and maintain continuity of operation and data.

An understanding of the nature of the benefits is critical to an informed choice of policies. However, **this memorandum does not take the next step of comparing the value of the public benefits to alternative uses of the public resources required, nor does it address directly the relative merits of public and private ownership.**

Since this memorandum was requested, Congress passed appropriations bill H.R. 3222, a provision of which prohibits the sale or transfer of the meteorological satellite (metsat) systems to the private sector. On November 28, 1983, President Reagan signed this bill into law (Public Law 98-166). Because the issues raised by the administration's proposal may be important in considering the disposition of other Government-developed technologies, OTA has retained discussion of metsats in this technical memorandum.

The metsat and Landsat systems not only serve different, if related, functions and constituencies, but also differ sharply in their developmental history and current status. The metsat systems are fully operational and run by the Government as part of its responsibility to provide weather services. Provision of these services has a long domestic and international history and a set of usages and established procedures. The Landsat system, by contrast, has until recently been entirely a research and development (R&D) effort, although in many respects it has been used as if it were operational. Landsat data are also fundamentally different in format, repeatability, and continuity from other remotely sensed images, such as aircraft photography, and therefore have not had an easy market niche. The Landsat program as a whole is clearly ready to shift from the earlier emphasis on R&D toward provision of routine services. Moderate-resolution land remote-sensing technology* is ready for full operational status. The question Congress now faces is whether the United States should treat land remote sensing as a fully appropriate Government operational activity (as it has with metsat), or transfer it to private hands under a variety of conditions, or drop it completely.

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[1] *Civilian Space Policy and Applications* (Washington, D.C.: U.S. Congress, Office of Technology Assessment, OTA-STI-177, June 1982), pp. 53-67.

This technical memorandum outlines the tangible and intangible public benefits that flow from operational remote sensing managed in the public interest. It provides a basis for deciding which requirements and conditions a private offeror could be asked to meet if the Government proceeds with transfer of the land remote-sensing system. Further, this memorandum provides a summary of what public social, economic, and political losses could accrue if the Government decided to drop civilian land remote sensing altogether, and leave the field to the French, Japanese, Soviets, and others.

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*That is, the multispectral scanner or equivalent systems, whose spatial resolution is about 80 meters.

BACKGROUND

The potential value of viewing Earth's atmosphere, land, and oceans from space for civilian purposes was recognized early in this Nation's development of space technology. The United States launched its first civilian remote-sensing satellite (a polar-orbiting weather satellite called TIROS) in 1960. TIROS provided the first civilian images from space.

The National Oceanic and Atmospheric Administration (NOAA) currently operates two civilian meteorological satellite systems. One is a polar-orbiting system that consists of two satellites (NOAA-N series) orbiting the Earth once every 102 minutes; the other consists of two geosynchronous satellites (GOES) that view the Western Hemisphere continuously and transmit images to Earth every 30 minutes. Both systems carry a variety of relatively low-resolution sensors (1,000 meters (m) or more at the surface of the Earth), which operate at several wavelengths to provide weather imagery and related data.

In 1972, the National Aeronautics and Space Administration (NASA) launched the first of a series of civilian land remote-sensing satellites (Landsat). Among other experimental devices, the first three satellites carried a sensor called the multispectral scanner (MSS), having a terrestrial spatial resolution of 80 m and operating in four spectral bands. Landsat 4, launched in 1982, carries the MSS, as well as a new sensor called the thematic mapper (TM), which has a terrestrial resolution of 30 m and operates in seven spectral bands.* Transmissions from Landsat are received globally by 3 U.S. and 10 foreign-owned ground stations. Landsat 4 is currently failing and could stop working at any moment. Landsat D′, which is the backup satellite for Landsat 4, is scheduled for launch in March 1984. Under current administration policy, this will be the last Government-owned land remote-sensing satellite unless new ones are ordered. NOAA now operates the Landsat system.

Although individual systems are typically designed to optimize the observations of the atmos-

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*Except for the 10.40 to 12.5 micron band which has a spatial resolution of 120 m.

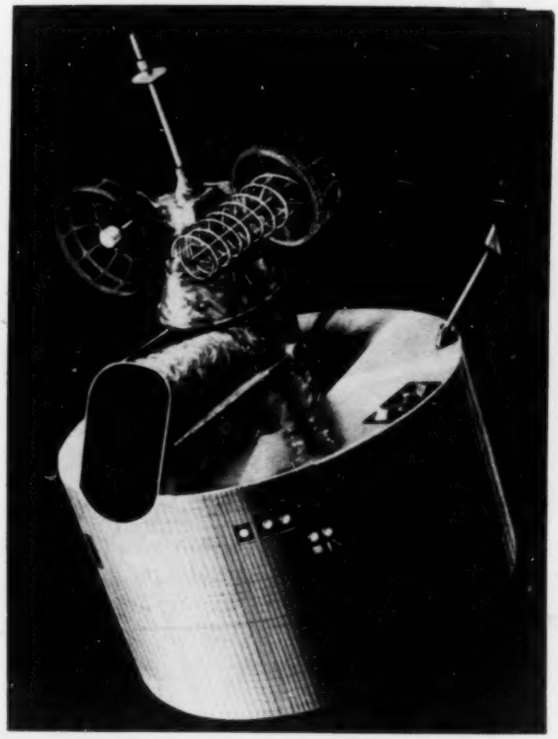

Photo credit: National Oceanic and Atmospheric Administration

Geostationary Operational Environmental Satellite (GOES series), artist's conception

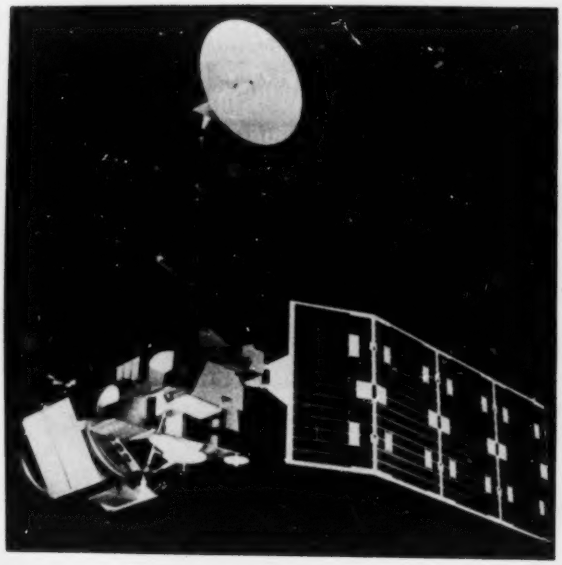

Photo credit: National Oceanic and Atmospheric Administration

Landsat 4, artist's conception

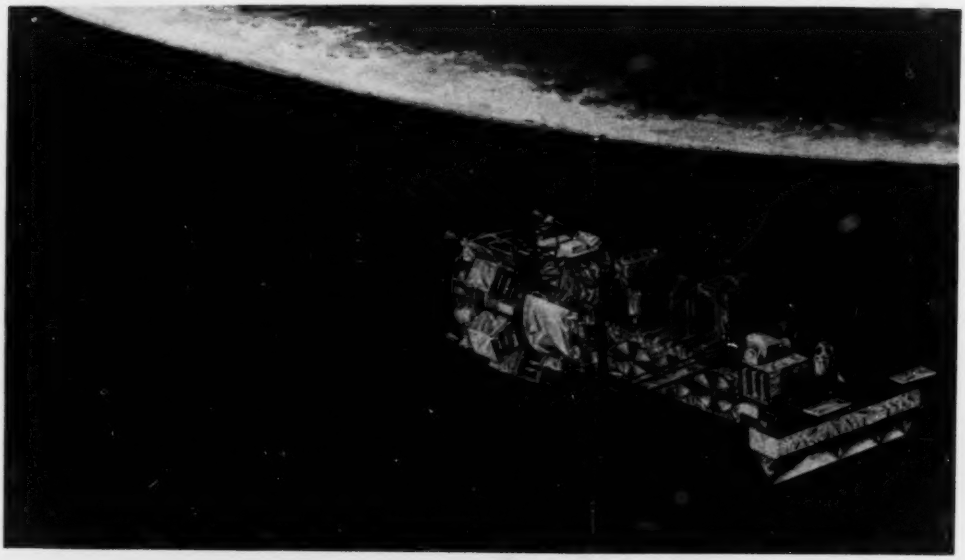

Photo credit: National Oceanic and Atmospheric Administration

NOAA-N series polar-orbiting environmental satellite, artist's conception phere, the land, or the oceans, sensors on board each satellite can also collect useful data on other components of the Earth. For example, agricultural managers use images from the meteorological satellites to estimate crop production, coastal-zone managers use Landsat data to study water pollution and pollution sources, and exploratory geologists use Seasat data to locate promising areas for exploration on land.

The Department of Defense (DOD) operates its own polar-orbiting meteorological satellite system. To a certain extent, DOD coordinates its meteorological operations with those of the civilian system. It makes use of data from the Landsat system, in addition to operating a system of surveillance satellites to serve national security needs.

Other countries are developing their own meteorological, land, and ocean remote-sensing systems. The European Space Agency (ESA), India, Japan, and the Soviet Union all currently operate meteorological satellite systems. The Soviet Union operates a land remote-sensing system; ESA and several other countries plan to launch land or ocean remote-sensing satellite systems by the end of the decade. Some of these systems will generate data directly competitive with data from the Landsat or related U.S. systems. By virtue of significantly higher resolution and a planned rapid delivery system, some will exceed Landsat's capacity to return useful data to users of remote-sensing data.

NASA's and NOAA's efforts with remote-sensing systems have demonstrated to domestic and foreign users, both inside and outside Government, that data from these systems can be highly effective in meeting their weather and resource information needs. In light of the potential commercial economic value that Earth resources remote-sensing data could have, the Carter administration, through Presidential Directive PD/54, directed that "Commerce will budget . . . to seek ways to enhance private sector opportunities" in land remote sensing. Although this directive left open the timetable and the means of a possible transfer of the Landsat system to the private sector, at the same time it committed the U.S. Government to provide a continuous flow of data from a land remote-sensing system through the 1980's. The Reagan administration decided early in its tenure to hasten the process of transfer; it further widened the scope of this policy by proposing that both the meteorological and land remote-sensing satellite systems be transferred to private ownership as soon as possible.

The Commerce Department set up a Source Evaluation Board (SEB) to draft the Request for Proposal (RFP) for transfer of the systems to the private sector. The RFP is intended to specify the Government's qualitative requirements for data for a period of time after transfer takes place, and to lay out the operational constraints that would be placed on the private offeror. The SEB issued a draft proposal for public comment on October 24, 1983. Prior to that time, it had solicited and received a number of comments from other Government agencies and from Congress. Commerce issued a revised RFP in January 1984 for industry's response. In keeping with the legislative prohibition on sale of the metsat systems, it no longer contains provisions for their transfer.

The RFP is long, technically thorough, and contains input from a wide variety of interested parties. In some respects, it is a very unusual RFP. For one thing, it leaves several important areas of Federal policy to be defined by the private sector. Further, in the absence of clear policy direction from either Congress or the administration, the private offeror runs an awkward and expensive risk of offering to invest and become involved in ways that could later be changed by policymaking legislation.

Congress held several hearings on the subject in 1983. The House and Senate are now considering legislation designed to encourage transfer of the Landsat system to private ownership reinforcing and specifically preventing similar transfer of metsats. Some members of both Houses favor transfer of the Landsat system; others feel it should remain a Government-owned and operated system.

INTERNATIONAL RELATIONS AND FOREIGN POLICY

Transfer of either system to the private sector would certainly affect our relationships with other nations. International issues related to transfer are among the most important and difficult to resolve satisfactorily. Consequently, the transfer proposal cannot possibly be approached as merely a domestic decision. Realistic planning for the disposition of the remote-sensing systems must address global concerns in the following areas:

International Relations and Foreign Policy Aims

Landsat and metsat data have served as useful and constructive instruments of U.S. foreign relations. These data have aided other countries to prepare in advance for severe weather conditions, and to map, manage, and exploit their own resources; they have also served to raise the general level of awareness about growing environmental problems throughout the world. **The data from both systems, and the equipment with which to process them, have provided the United States with access to, and influence in, many other countries.**

Although the private sector is technically capable (given adequate financial incentives) of providing the data promptly to meet the requirements of the Federal Government and other potential customers, commercial objectives may conflict with U.S. foreign policy objectives. **Constraints on a private firm that are sufficient to protect U.S. foreign policy objectives could well make such an enterprise unprofitable or require a large and continuing Government subsidy to make the enterprise viable.**

Data Sales

The United States has followed the policy, consistent with the practice of other countries, of providing meteorological data freely and without charge. After exploring the feasibility of charging for meteorological data, which raised ire and concern in other countries (especially those that participate in the data gathering), the administration decided to continue the earlier policy. If the metsats were to be transferred to the private sector, the Government would presumably purchase the data from the operating firm and then distribute them free of charge to other countries. **Since the United States receives free of cost more vital meteorological data from other countries than it gives away, and since providing global weather data is a public good, maintenance of this data policy would continue to benefit the United States.**

Landsat data have always been sold to non-U.S. Government users, and they have been made available to all purchasers on a nondiscriminatory basis. Indeed, the data policy of the Landsat program can be considered to be a cornerstone of the U.S. "open skies" policy and of the use of space for peaceful purposes. By following this policy, the United States has been able effectively to blunt criticism of other activities, such as the operation of classified surveillance satellites. It has also been able to demonstrate to the entire world its adherence to the principle of the free flow of information. **It is a powerful message to send to all governments, especially those opposed to the open interchange of ideas and information, that Landsat data are available even to our political and economic adversaries at the same price and under the same terms as to our friends.**

Yet, if the transfer to the private sector were made, potential owners would exert strong pressure to be allowed to set their own data sales policies in order to maximize profitability. Such a posture would frustrate the very policy the United States has fought so hard and so long to maintain in the United Nations and in its foreign relations. **In view of the continued importance of the "open skies" principle to the United States, altering the principle of nondiscriminatory sale of land remote-sensing data would be harmful to many U.S. foreign policy interests, not just those involving outer space.** Whether or not the Government decides to continue the nondiscriminatory policy, **any charter for a private firm should be unambiguous with respect to the data distribution policies the firm could pursue.**

Value-Added Services

To date, most of the revenue from the use of remote-sensing data has been earned by those corporations that process, analyze, add other information, and/or interpret the data for themselves or for others (the so-called value-added industry). The value-added companies constitute a small, but growing, specialized industry. Most bidders for a remote-sensing system would want to participate in the value-added business. **The primary economic value of the data from the meteorological satellites is in warning of impending severe or unusual weather. Since receiving terminals are relatively inexpensive, most countries and many organizations can afford to own and operate them. For meteorological data, allowing a data supplier to sell value-added services as well as data appears to raise no special concerns in developing countries as long as the raw data remain freely available to everyone with the capacity to receive them.**

High-resolution land remote-sensing data and the ability to analyze them are potentially powerful tools for resource development. Many developing countries have expressed the fear that if the company owning the data collection and distribution system were also allowed to offer value-added services, it might take special advantage of having control over the acquisition and distribution process to make its own value-added services more timely or more complete than the services of its competitors. Under such conditions, the company, and its most favored customers, could obtain economic leverage over countries that lacked the facilities and personnel capable of interpreting the data. **Therefore, from the standpoint of maintaining good relations with developing countries, it may be appropriate for the United States to restrict the private data distributor from entering into the value-added business, or to regulate it closely to prevent such a company from exerting unfair economic leverage over others.** As competition from foreign or even other domestic systems grew, it should be possible to relax such restrictions. Alternatively, the Government could require data analyses to be sold openly as well.

U.S. Technological Leadership

The existence of metsat ground stations, owned and operated by over 125 countries, and the much more expensive Landsat ground stations in 10 countries, constitute an eloquent statement of U.S. leadership in sucessfully applying high technology for the benefit of all mankind. The United States has also participated with both industrialized and developing countries in pursuing applied research in the uses of the data. **It is critical to the continuing R&D of remote-sensing technology and the growth of the data market for the United States to maintain its cooperative basic and applied research programs with other countries, both to advance U.S. research objectives and to retain U.S. leadership in the technology of outer space.**

Cooperation With Developing Countries

Through its international cooperative projects with developing countries, the United States has advanced the state of the art in remote sensing, and provided access to information and processes that those countries would not have been able to afford to develop unilaterally. This cooperative approach has materially helped such countries to cope with the enormous human and physical problems of resource management, especially in isolated, rural areas.

In an era of rising costs and decreasing budgets, it may be increasingly difficult for the Agency for International Development (AID) and other U.S. organizations to provide data and other research support in remote sensing, yet U.S. Government agency technical programs are largely responsible for the development of the international community of users of metsat and Landsat data, and the concomitant market for Landsat data products. **If the transfer to the private sector is made, it will therefore be important to assure that appropriate Government funding is continued for these projects, and that access to data will also continue.** It will also be important to involve private value-added companies in these projects.

International Legal Issues

The United States helped to formulate and is now party to four major international treaties and agreements that may affect the operations of privately owned Earth remote-sensing systems. Of greatest importance to potential private owners of remote-sensing satellite systems is the **1967 Outer Space Treaty**, article VI of which requires "continuing supervision by the appropriate State party to the Treaty." At the least, this provision suggests some form of licensing and Government-imposed regulations for private space system operators.

In regulating a private land remote-sensing system, the Department of State, Department of Commerce, or other concerned Federal agencies have the opportunity to develop imaginative strategies and institutions for working with the private sector in this technology. The form of these strategies and institutions is particularly important because land remote-sensing data, by the nature of their information content, raise the sensitivities of other countries. **The Department of State's Bureau of Oceans and International Environmental and Scientific Affairs (OES), which would likely be charged with regulatory responsibility over international questions, would have to strengthen its technical expertise in space and its commitment to using space technology as part of the foreign policy of the United States. Such regulations could bring U.S. foreign policy objectives into direct conflict with the profit motives of private enterprise.**

Some countries maintain that they should have priority access to data derived from the sensing of their territory; others have argued that their consent should be obtained before these data are transferred to third parties. The United States maintains that a policy of free collection and dissemination of primary data is both supported legally and encouraged by the **1967 Outer Space Treaty** and article 19 of the U.N. **Universal Declaration of Human Rights.**

Our historical policies of nondiscriminatory data sales and the free flow of information have served us well in deflecting attempts to restrict the right to sense other countries or to make those data available to third parties. Should transfer to private ownership result in discriminatory access to data—and a reduction in technical assistance and concessionary sales policies aimed at making these data less accessible to less developed countries—the U.S. position about "open skies" would have to be modified, with attendant losses to U.S. foreign policy objectives.

Future International Coordination

The United States currently participates in the deliberations of several international groups that set or coordinate standards for remote-sensing systems. If transfer of the Landsat system takes place, the Government should spell out clearly how private firms would interact with the Department of State and other U.S. agencies having cognizance over these matters.

Landsat Foreign Ground Stations

If the transfer takes place, the Memoranda of Understanding between NOAA and the foreign ground stations would become null and void. Yet the foreign ground stations provide data of significant importance to the U.S. Government. **In order for the private firm to supply the required data to the Government, in the absence of a system like the Tracking and Data Relay Satellite System, it may be essential for the firm to be able to enter into agreements with the foreign governments who own the receiving stations. Some countries may be unwilling to do so without major concessions regarding data distribution policy on the part of the private owner. In other words, foreign owners may insist on placing restrictions on sales of data to their adversaries.**

DOMESTIC PUBLIC GOODS

U.S. remote-sensing programs have contributed significantly to the domestic public welfare. The daily contributions of the meteorological satellites are visibly reflected in the daily media forecasts. Landsat's contribution is less often publicized, but the data it provides make possible new cost-effective ways to assess, manage, and exploit Earth's resources and environment. Landsat data are used for agriculture (to indicate crop stress and to forecast crop yield), forestry (to reveal the state and extent of forest resources and determine appropriate replanting strategies), resource exploration (nonrenewable resources), environmental monitoring and coastal zone management, cartography, and resource management.

State and Local Government

A fully integrated communications network for receiving and disseminating satellite meteorological data already exists in the U.S. National Weather Service, which adds these data to terrestrial observations and distributes them to the States and local communities in the form of long- and short-range weather forecasts. States and local news media use these data to warn citizens of impending weather conditions, including severe weather.

Several States have also begun to integrate Landsat data into their long-term planning, and to add them to computerized information retrieval systems. **However, the high cost of large computers and software and the expense of training and maintaining personnel, combined with uncertainties about Federal policy, are inhibiting the States from relying more heavily on Landsat data.** Further, some States that now use Landsat data to support their planning efforts are worried that transfer of the system to private hands would cause sharp rises in the prices of data over a short time. In order to cut costs, many States share Landsat data purchased from the Government with other States, particularly in border areas where Landsat scenes cover land in two or more States.* **States express concern that private owners would copyright the data in order to inhibit copying and trading them, which would also raise the costs of using Landsat data.**

Continuing Research

Important for satellite remote sensing is research on how to apply the data to environmental and resource problems as well as on improving sensors and related hardware. Although meteorological satellites have been operational for years, experimenters continue to discover ways to use their low-resolution data to solve some resource problems. For example, these data now serve as important adjuncts to the use of Landsat data for agricultural predictions. **It will be important to continue university, private sector, and Government research on applying meteorological data to resource problems. In addition, there is a need for continuing improvements to the meteorological sensors. The present research program within NOAA is inadequate.**

Although the system to produce data from the MSS sensor aboard Landsat 4 is appropriately termed "operational," many of the techniques to use the data effectively are by no means well understood. **Thematic mapper (TM) data will require considerable experimentation in order to learn how to make the best possible use of them. The universities could play a strong role in such research. Without a continuing source of data and continued experimentation in the public and private sectors with applying both MSS and TM data, the market for data and data products will not develop and potential benefits will remain unexploited by the United States.**

NASA plans to fly a variety of advanced experimental remote sensors on the space shuttle. However, there is also a great need to develop long-life operational sensors and associated processing hardware that can be used for commercial purposes. **Smooth incorporation of new hardware into operational systems generally mandates evolutionary, not revolutionary, changes in design and system capacity.**

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*Sharing data by copying data tapes or photographic products is now a common practice in Federal agencies, private industry, and the universities, as well as in State and local government.

Maintenance of Archives

Data gathered from meteorological satellite observations contribute to our knowledge of long-term weather patterns. In particular, the National Climate Program within NOAA assembles these data and combines them with other satellite and terrestrial data to produce world climate models. **In order to continue the research on weather and climate, it will be important to continue to archive meteorological satellite data and to maintain continuity of the data format.**

The EROS Data Center (EDC) currently maintains an archive containing most of the data it receives. However, most foreign data are not included in the archive, nor is it possible to purchase most foreign data directly from EDC. Customers must generally purchase their images of foreign land areas from the appropriate foreign ground stations. The expense of maintaining a complete archive of all the data ever received from the Landsat system is too great. However, it should be possible to construct a complete set of cloud-free images of MSS data for the entire world. To date, because of lack of funds, this has not been done, although NOAA and NASA recognize the value of such an archive, especially for mapping, land-use planning, and for mineral exploration. **The Government would have to decide whether the limited archive maintained at EDC would be transferred to the private sector and, if so, under what conditions. If the archive is transferred, safeguards to protect it from later deterioration or destruction should be instituted so that all interested parties will continue to have access to these data without copyright restrictions.**

University Programs

In addition to their role of developing and instructing in the use of new technologies, universities and other not-for-profit organizations have carried out research in using Landsat data for themselves, State and local governments, private industry, and the Federal Government. At present they face two major concerns: 1) the steeply rising prices of Landsat data and the concomitant decrease of Federal research support have caused some universities to reduce severely their research and teaching programs; and 2) the universities express worries that both the operational and research aspects of the U.S. Landsat program lack direction. **From the point of view of university researchers and teachers, these uncertainties make the prospects for the future grim, presaging further reductions in their teaching and research programs related to land remote sensing. Yet these institutions play a major role in technology transfer, both in the United States and abroad.**

CIVILIAN FEDERAL GOVERNMENT REQUIREMENTS

Data from the meteorological satellites have been used directly by the various Federal mission agencies either as they are transmitted to Earth, or after being processed and integrated with other weather data by the National Weather Service. If the process of transfer of the metsats to private ownership had continued, the Government would have offered to control, and pay for, the provision of required domestic and international meteorological data. It would have left to the private sector the design and operation of future satellites, sensors, and related equipment to ensure that the Government's needs for data were met.

For several years, data products derived from the Landsat MSS sensor have been applied by the mission agencies to specific resource management and evaluation tasks. In most cases, these data products have become the standard for the remote-sensing users, both within and without the Government. Although TM data will continue to be used for research purposes, **because of the difficulties and expense of processing the enormous volume of data represented in a TM scene, they will see relatively limited use. MSS-type data will continue to be of general interest to large parts of the user community for some time to come.**

In part this interest exists because the user community is accustomed to using the data, but for many users, the data's four-band multispectral characteristics and synoptic view are often of greater importance than their spatial resolution. **Although it will be important to continue to study the applicability of advanced data such as TM, which incorporates seven spectral bands, for Federal mission agencies, data equivalent to MSS in format, spectral and spatial characteristics will satisfy most civilian Federal needs for the rest of the 1980's.**

Even if the private sector assumes responsibility for providing remote-sensing data for the U.S. Government, it will be necessary for the Government to maintain oversight authority over such corporations to assure that they continue to provide Federal data needs. **It seems appropriate to designate a single lead agency to supervise and regulate all U.S. civilian remote-sensing activities. However, to protect both Government and private interests, it will be necessary that the agency act in such a way as not to stifle realistic opportunities for a private owner to exercise initiative and flexibility in providing data responsive to a worldwide market, including the private U.S. market.**

Government Data Requirements

If transfer of the Landsat system to private ownership were made soon, (i.e., while Landsat 5 is still functional*), it would be appropriate for the new owner to maintain data products and service equivalent to, or better than, the Government now provides using the MSS sensor. However, one of the reasons for transferring the system to private hands would be to achieve better data products, delivery, and services than now exist. **Thus, as the privately owned system evolved, the Government would be likely to demand improved service and products.**

As U.S. private satellites begin to incorporate improved sensors capable of higher resolution and pointing, as the French SPOT satellite has been designed to do, it will be tempting for the Government as well as other customers to ask the corporation to respond to special data needs, in addition to supplying routine data. However, such special tasking can only be accomplished at an extra cost, because it takes the satellite away from routine tasks. Because this differential pricing (for differing levels of service) also has the potential for being discriminatory, it should receive careful consideration and rules for handling it should be developed.

Alternative Systems

The Landsat system provides a unique capacity. No other technique in the world provides the ability to obtain reasonably detailed data (i.e., each minimum unit of Landsat MSS data represents 1.1 acres on the ground), over the entire Earth, and at a repetitive frequency that allows most temporal changes to be monitored effectively. However, in order to derive the maximum user benefits of this technology, it will be necessary to find ways to reduce sharply the system costs while improving delivery. **System studies by several private companies have shown it may be possible to achieve cost reductions of up to 50 percent for an operational system. If the Government decides to maintain its own civilian land remote-sensing system, it will be essential to find additional ways to reduce system costs. Because R&D is so expensive, major cost cutting for operational services implies that substantial R&D can no longer be done while providing a high level of routine services.**

NATIONAL SECURITY REQUIREMENTS

The ability of the United States to collect extraterritorial information of military and intelligence value was suddenly and dramatically improved in the early 1960's with the development and operation of classified meteorological and reconnaissance satellite systems by DOD. Satellite programs provide, among other things, essential data about areas of the world where other types of U.S.

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*Landsat 5 will be called Landsat D′ until it is launched and operating in March 1984. Its nominal lifetime in orbit is 3 years for the spacecraft, 3 years for the MSS, and 1 year for the TM.

access is restricted. So long as both the civilian unclassified programs and the military classified programs are under the direct control of the Federal Government, the activities of both can be coordinated and controlled in the national interest. **However, placing remote-sensing programs in the private sector may make it very difficult to continue appropriate coordination between systems and control over data delivery.**

It is little appreciated that the intelligence and defense communities, taken together, currently are the largest users of Landsat data within the Federal Government. If there were no appropriate civilian Government system or sufficient safeguards on a privately owned system, these communities might find it necessary to build and operate their own system, thereby diminishing any expected budget savings.

DOD Oversight of Technical Specifications

NASA, in collaboration with other Federal agencies, academic institutions, and industry, has carried out a substantial program of experimentation and demonstration of sensors and data-processing techniques for land remote sensing. NASA has pursued its research in cooperation with DOD as provided for in the 1958 National Aeronautics and Space (NAS) Act. Until recently, the ground resolution of the civilian systems has not been sufficient to detect objects of significant military interest. However, **the development of advanced high spectral and spatial resolution civilian sensors in the United States and abroad, and the prospect of private sector entry into the realm of land remote sensing, necessitate a reexamination of U.S. and other national policies regarding technology development and technology transfer. Areas that should be examined carefully include the limits that should be placed on the ground resolution of space-borne sensors, their spectral characteristics, and on sophisticated data-processing techniques. However, in the face of the development of advanced foreign systems, it will be difficult for DOD to exert much control over advances in U.S. civilian hardware and processing techniques without making it impossible for the United States or its firms to compete in the world market.**

Preemption by the Military in Time of Emergency

The increased spectral and spatial resolution of TM or other land remote-sensing systems make the data they provide of increasing interest to DOD and the intelligence community. These data could serve as a supplement to other data collection means at any time. **It will be essential to spell out clearly the particular requirements of DOD and the intelligence community for hardening of the system's electronics, and the system specifications, as well as the conditions under which the private system could be preempted. Meeting these special requirements will add cost. If the private owner were to be required to meet them without specific compensation, data prices would be extremely high for all users, which would inhibit the development of a commercial market for data. If the Government were to pay for these additional capabilities, such support would constitute an additional subsidy of the system, beyond the basic ones of no competition and fixed data purchases.**

FOREIGN COMPETITION

It is clear that other countries, building on the experience gained from U.S. applications technology as well as on their own capabilities, see the development of meteorological, land, or ocean remote-sensing satellites as an integral component of their entry into space. In addition to constructing systems competitive with the U.S. Landsat system, they are also moving to develop systems that will sense the physical parameters of the oceans and the coastal waters. The United States, though it has a program within NASA to develop new sensors to fly intermittently on the shuttle, has no plans to develop civilian operational systems for land or ocean remote sensing that would provide continuous data over the long term with repeat coverage.

In order to maintain U.S. leadership in applications of space technology, it will be important for the United States to maintain continuity of data delivery. This is likely to require Government subsidy. It will also be important for the Government and the private sector to sustain a vigorous program of research in both space systems and the applications of the data such systems supply to the solution of a wide range of terrestrial problems. If the United States wishes to maintain leadership in this technology, it will be essential that the technology and the data it produces, whether publicly or privately owned, remain an integral component of U.S. domestic and foreign policy.

Chapter 2

Introduction

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Chapter 2
Introduction

This technical memorandum explores the major policy-related issues raised by the proposed private ownership of satellite-based civilian remote-sensing systems. It responds to requests from the Committee on Science and Technology of the U.S. House of Representatives to provide information that would help the committee fulfill its oversight and legislative responsibilities. Specifically, the committee requested that OTA "address the requirements or constraints relating to international and national security concerns."[1]

This memorandum is designed to aid Congress in determining the appropriate requirements and conditions for private sector ownership and/or operation of the U.S. land remote-sensing systems. It also provides information and analysis that will be useful for Congress as it develops and considers legislation for transferring remote-sensing satellite systems to the private sector. It does not reach any explicit judgments about whether a transfer of remote-sensing services and data to private hands is either feasible or desirable. Rather, OTA's analysis discusses what a private owner and/or operator might be required to do in order to meet existing or projected U.S. obligations to the international community, to enhance national security, and to preserve the public benefits of civilian remote sensing from space.

Although the value of remote sensing must constitute part of the analysis of potential requirements, this memorandum neither analyzes the potential market for remote-sensing data, data products, and services, nor judges the benefits versus the costs of maintaining these services in the Federal Government as compared to transfer to the private sector. However, it enumerates many of the concerns that users of data from the system have expressed about transfer to the private sector. It leaves it to Congress to judge the relative importance of potential requirements that might be imposed on the private sector.

Shortly before this technical memorandum was completed, Congress voted to keep the meteorological satellite systems in the hands of the Government and directed the administration to cease preparation of a request for proposal to transfer these systems to the private sector.[2] However, because the issues the proposed sale of the meteorological satellites raises are typical of the movement of technology from the Government to private hands, and of the decisions that must be made vis-à-vis public and private goods, OTA has retained the analysis of meteorological satellite systems.

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[1] Letter from U.S. House of Representatives Committee on Science and Technology, July 20, 1983; see also letter from Government Operations Committee, September 1983.

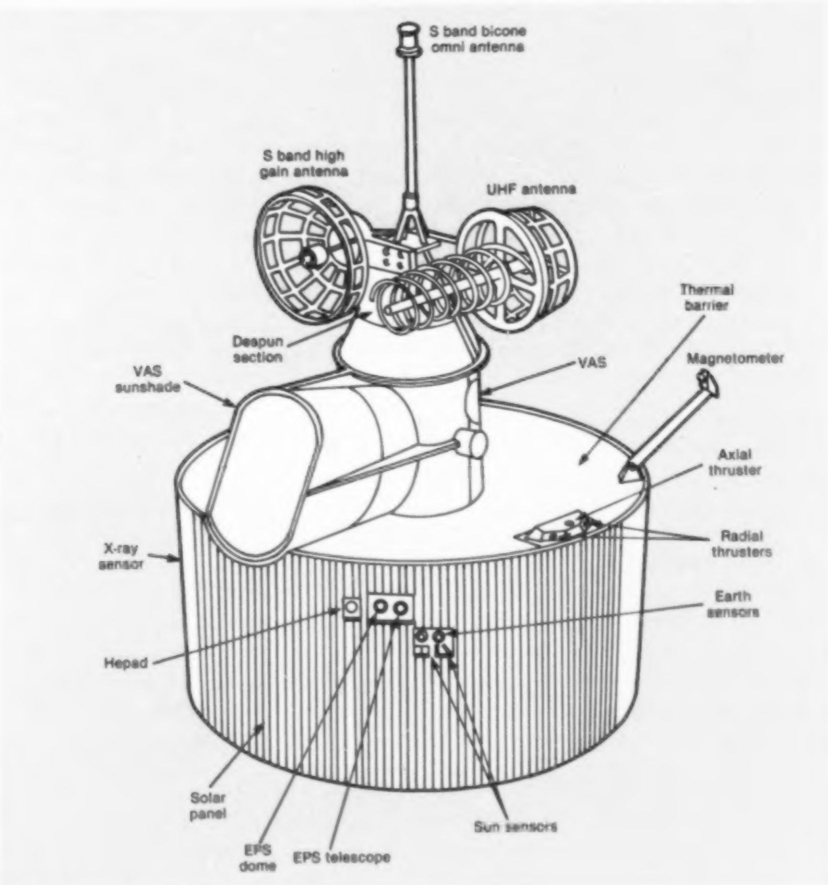
[2] Appropriations bill H.R. 3222, November 1983.

DEVELOPMENT AND STATUS OF REMOTE SENSING FROM SPACE

The scientific and user community recognized early in the development of space technology the potential value of sensing Earth's atmosphere, land masses, and oceans from space for civilian purposes. The first civilian remote-sensing satellite was a polar-orbiting weather satellite called TIROS, launched by the United States in 1960. TIROS provided the first civilian images from space.

Subsequent improvements in the polar orbiters by the National Aeronautics and Space Administration (NASA), which until recently has conducted much of the research and development (R&D) on new sensors, and the National Oceanic and Atmospheric Administration (NOAA), which operates the meteorological satellite systems, have led to a powerful system of two orbiters that circle Earth every 102 minutes and provide complete

GOES Satellite



SOURCE: National Oceanic and Atmospheric Administration.

MISSION: Repetitive observations of the earth disk and overlaying atmosphere in the field of view; measurements of solar x-rays and the proximate space environment; collection and relay of data from platforms at or near the earth's surface; broadcast of data and environmental information.

ORBIT: 35,800-km geosynchronous. GOES East over equator at 75° W; GOES West at 135° W.

SENSORS AND FUNCTIONS:

- **Visible and Infrared Spin Scan Radiometer (VISSR) Atmospheric Sounder (VAS):** The VAS is a visible and infrared radiometer capable of providing both multi-spectral imaging and dwell sounding data. It possesses eight visible and six infrared detectors. Positioning a filter wheel allows selections from among 12 spectral bands with central wavelengths between 3.9 and 15 µm. VAS scans west to east in conjunction with spacecraft rotation at 100 rpm; a stepping mirror provides pole to pole scanning. Resolutions are 1-km in the visible and 7- or 14-km in the infrared, depending upon the selection of IR detectors. Visible imaging data are provided routinely every 30 minutes by each spacecraft during daylight and infrared (7-km) imaging data, on the same schedule, are provided day and night.

  Space Environment Monitor (SEM): Composed of 4 subsystems.

  (1) X-Ray Sensor: Provides data on solar x-ray activity in two wavelength bands: 0.5-3.0Å and 1-8Å.

  (2) Energy Particle Sensor: Determines intensity of charged particle flux in the following ranges:

  Protons - 0.8 to 500 MeV, 7 log ranges
  Alphas - 3.2 to 400 MeV, 6 log ranges
  Electrons >2 MeV, 1 range

  (3) High Energy Proton and Alpha Detector (HEPAD): Protons in the 379-keV range, alpha particles in the 850-keV range.

  (4) Magnetometer: Monitors magnitude and direction of ambient magnetic field, parallel field (± 1200γ), and transverse field in 4 selectable ranges (± 50γ, ± 100γ, ± 200γ, or ± 400γ).

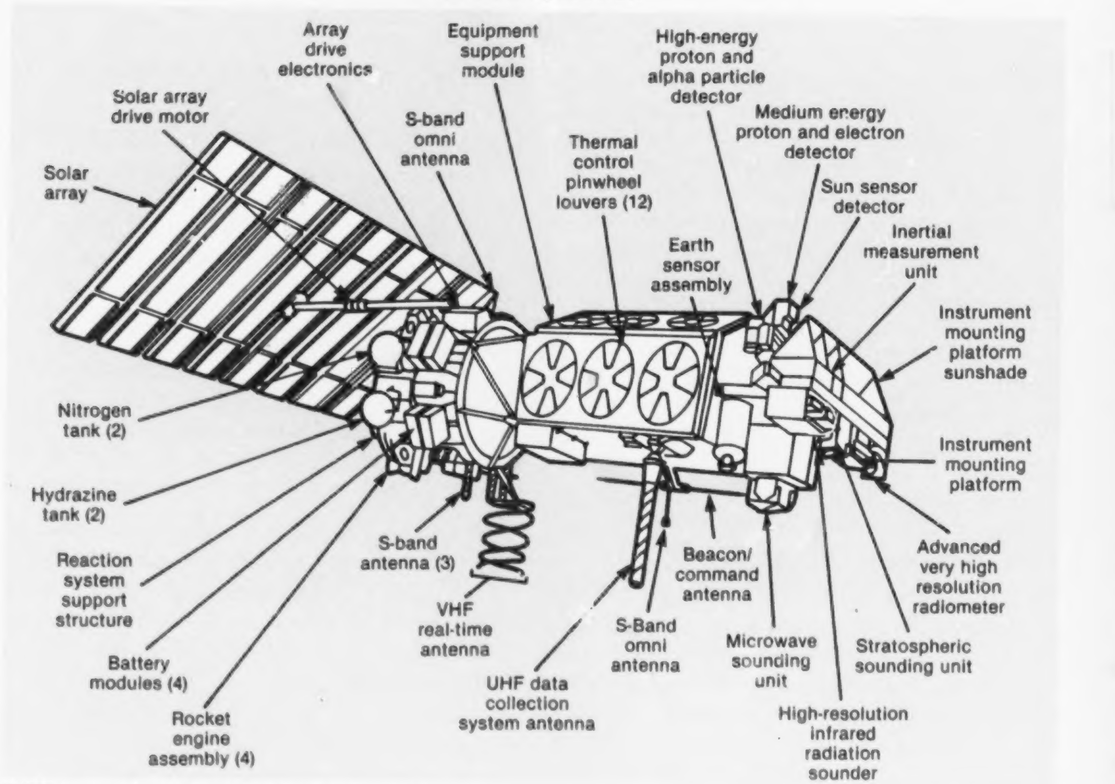
- **Data Collection System (DCS):** Relays UHF interrogations to, and data from, sensor platforms reporting environmental data.

DIRECT BROADCAST: Broadcasts available to any ground station within range.

- **WEFAX:** Retransmission of processed data at 1691.0 MHz. Along with meteorological charts, GOES imagery at 8-km resolution and NOAA imagery at 8- to 12-km resolution are transmitted. A daily operational message is transmitted that provides schedules and contents. A basic ground capability costs about $8,000 (U.S.) in 1981.

- **Stretched Sensor Data:** A retransmission, at a reduced rate, of the data burst that occurs during the 20° angular sweep of VAS detectors across the earth. The transmission is on S-band at 1687.1 MHz. A basic ground station that includes a limited product capability costs about $150,000 (U.S.) in 1981.

NOAA-N Spacecraft


Array drive electronics
Equipment support module
High-energy proton and alpha particle detector
Solar array drive motor
Medium energy proton and electron detector
S-band omni antenna
Thermal control pinwheel louvers (12)
Solar array
Sun sensor detector
Inertial measurement unit
Earth sensor assembly
Instrument mounting platform sunshade
Nitrogen tank (2)
Instrument mounting platform
Hydrazine tank (2)
Reaction system support structure
S-band antenna (3)
Beacon/ command antenna
Advanced very high resolution radiometer
VHF real-time antenna
S-Band omni antenna
Microwave sounding unit
Stratospheric sounding unit
Battery modules (4)
UHF data collection system antenna
Rocket engine assembly (4)
High-resolution infrared radiation sounder

SOURCE: National Oceanic and Atmospheric Administration.

MISSION: Collect global data on cloud cover, surface conditions such as ice and snow, surface and atmospheric temperatures, and atmospheric humidity, measure solar particle flux, collect and relay information from fixed and moving data platforms, provide continuous data broadcasts

ORBIT: 833- and 870-km circular, 98 89° inclination, ~14-1 4 revs day

SENSORS AND FUNCTIONS:

- **Advanced Very High Resolution Radiometer (AVHRR/2)**
  1 1-km resolution, ~2600-km swath width

Channels	Wavelengths (μm)	Primary Uses
1	0 58 - 0 68	Daytime cloud/surface mapping
2	0 725 - 1 10	Surface water delineation, ice and snow melt
3	3 55 - 3 93	Sea surface temperature, nighttime cloud mapping
4	10 30 - 11 30	Sea surface temperature, day and night cloud mapping
5	11 50 - 12 50	Sea surface temperature, day and night cloud mapping

- **TIROS Operational Vertical Sounder (TOVS)**:
  A 3-sensor atmospheric sounding system

(1) **High Resolution Infrared Radiation Sounder (HIRS/2)** 17 4-km resolution

Channels	Wavelengths (μm)	Primary Uses
1-5	14 95 - 13 97	Temperature profiles, clouds
6-7	13 64 - 13 35	Carbon dioxide & water vapor bands
8	11 11	Surface temperature, clouds
9	9 71	Total O_3 concentration
10-12	8 16 - 6 72	Humidity profiles, detection of thin cirrus clouds
13-17	4 57 - 4 24	Temperature profiles
18-20	4 00 - 0 69	Clouds, surface temperatures under partly cloudy skies

(2) **Stratospheric Sounding Unit (SSU)**: 147 3-km resolution

Channels	Wavelengths (μm)	Primary Uses
1-3	15	Temperature profiles

(3) **Microwave Sounding Unit (MSU)**: 105-km resolution

Channels	Frequencies	Primary Uses
1	50 31 GHz	Temperature soundings through clouds
2	53 73 GHz	
3	54 96 GHz	
4	57 95 GHz	

- **Space Environment Monitor (SEM)**: Measures solar particle flux at spacecraft
  (1) **Total Energy Detector (TED)**: Solar particle intensity from 0 3- to 20-keV
  (2) **Medium Energy Proton and Electron Detector (MEPED)**: Protons, electrons, and ions in 30- to 60-keV range
- **ARGOS Data Collection System (DCS) (French)**: Collection and relay of data from fixed or moving automatic sensor platforms, determines location of moving platforms

DIRECT BROADCAST: Continuous data broadcasts available to any receiving station within range

- **Automatic Picture Transmission (APT)**: Visible and infrared imagery at 4-km resolution VHF broadcasts at 137 50 or 137 62 MHz Basic ground equipment costs about $25,000 (U S) in 1981
- **High Resolution Picture Transmission (HRPT)**: Visible and infrared data at 1-km resolution S-band broadcasts at 1698 0 and 1707 0 MHz Basic ground equipment costs about $250 000 (U S) in 1981
- **Direct Sounder Broadcast (DSB)**: TOVS data transmitted for use in quantitative programs Broadcast at 136 77 or 137 77 MHz (Beacon Frequency) and in the HRPT data stream Conventional ground receiving station required but specialized data processing is necessary to produce environmental information

coverage of Earth's atmospheric parameters every 6 hours. These NOAA N-Series satellites also carry the ARGOS Data Collection System provided by France, which collects and relays environmental and other data from ground-based automatic sensor platforms. The polar-orbiting meteorological satellite system is now augmented by two geostationary satellites (GOES) that provide low-resolution visible and infrared coverage of the western hemisphere every 30 minutes.

Both systems are integral parts of the U.S. weather and climatological systems and constitute a major source of timely weather data to the rest of the world. They also comprise a major source of data for studies of long-term weather trends and climatological studies.[3] By international agreement, weather data, including those gathered by satellite, are shared with the world community freely and at no cost. In return, the United States receives satellite and other weather data at no cost from other countries all over the world.

Aircraft-based experiments with multispectral land remote-sensing systems started before the Space Age, but were strengthened when NASA launched the first land remote-sensing satellite, Earth Resources Technology Satellite (ERTS), in 1972. This satellite was later renamed Landsat 1 and was followed by Landsats 2 and 3 in 1975 and 1978, respectively. In addition to other research devices, all three satellites carried a sensor called the multispectral scanner (MSS), having a spatial resolution at Earth's surface of about 80 meters and covering four spectral bands. The output of this sensor, transmitted to Earth, then corrected and stored, constitutes the primary archival library of Landsat data, extending back to 1972. Landsat 4, which was launched in 1982, carries both an MSS sensor and an experimental thematic mapper (TM) sensor, having a nominal spatial resolution of 30 meters on Earth, and providing seven spectral bands of data.*

Developed and procured by NASA, the Landsat system (Landsat 4) is now operated by NOAA. At the present time, no data can be received directly from the TM because of a failed X-band transmitter aboard the satellite. Limited TM reception is possible through the Tracking Data and Relay Satellite System (TDRSS) when the latter is available for use. In addition, two of the four solar panels that provide power to the spacecraft have failed. Landsat 4 consequently has a highly limited lifetime. NOAA plans to launch the backup satellite to Landsat 4, Landsat D′, this month. After launch it will then be named Landsat 5.

NASA's and NOAA's efforts with the Landsat system have demonstrated to a small but dedicated group of customers, both within and without the Government, that satellite data can be highly effective in meeting their resource information needs.[4]

In 1978, NASA launched the first dedicated ocean observation satellite, Seasat-A. Designed to last for at least 1 year, Seasat-A failed after only 3 months in orbit. During that period its active and passive microwave sensors (including a synthetic aperture radar) returned important new data on the characteristics of the oceans, sea ice, and a variety of terrestrial features. Despite Seasat's high degree of technical success, no follow-on civilian oceanographic satellite has been authorized.

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[3] *Civilian Space Policy and Applications* (Washington, D.C.: U.S. Congress, Office of Technology Assessment, OTA-STI-177, June 1982), app. E.

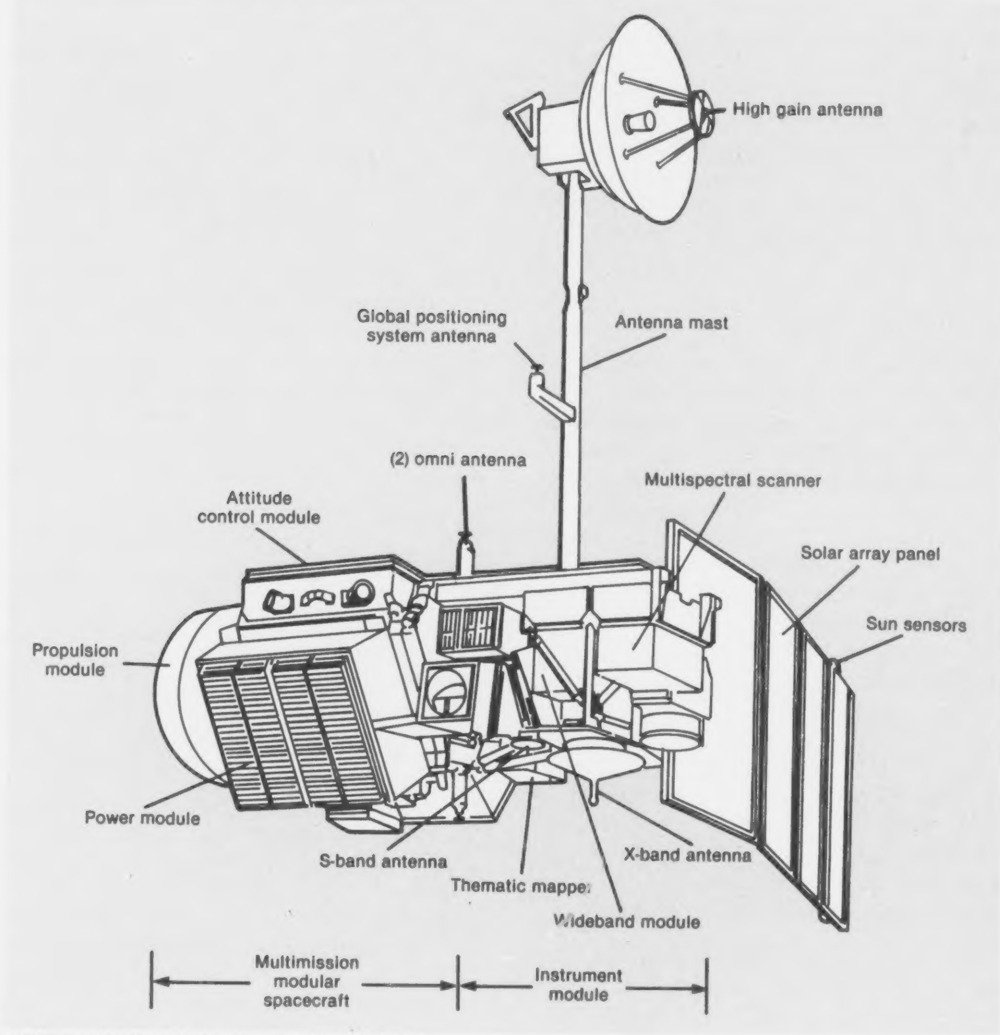
*The thermal band at 10.40 to 12.5 microns has a spatial resolution of 120 meters.

[4] *Civilian Space Policy and Applications*, op. cit., pp. 53-67.

REMOTE-SENSING POLICY

Although the potential utility of images gathered by satellite of atmospheric conditions and of the surface of the land and ocean were recognized by those conceiving the systems, few considered operating the systems as commercial entities. However, as Federal, State, and local governments and universities and industrial firms began to work with the data from the Landsat system, they realized that these data were often a cost-effective substitute for older (aircraft) methods of

Landsat-5 Spacecraft


High gain antenna
Global positioning system antenna
Antenna mast
(2) omni antenna
Multispectral scanner
Attitude control module
Solar array panel
Sun sensors
Propulsion module
Power module
S-band antenna
Thematic mapper
X-band antenna
Wideband module
Multimission modular spacecraft
Instrument module

SOURCE: National Oceanic and Atmospheric Administration.

MISSION: Collect remotely sensed. multispectral land data. broadcast data for receipt at ground stations operating under formal agreements

ORBIT: 705-km sun synchronous 16 day repeat cycle

SENSORS AND FUNCTIONS:

Multi-spectral Scanner (MSS): The MSS is the specified operational sensor Swath width is 185-km: resolution is 80-m

Sensor Wavelengths (μm)	Primary Uses
0.5 - 0.6	Movement of sediment laden water delineation of shallow water areas
0.6 - 0.7	Cultural features
0.7 - 0.8	Vegetation. boundary between land and water. landforms
0.8 - 1.1	Penetration of atmospheric haze vegetation. boundary between land and water landforms

Thematic Mapper (TM): The TM is a NASA experimental sensor It will come on-line operationally after it has been proven by NASA and an appropriate ground system has been constructed It is designed to provide 30-m resolution except for 120-m resolution in the thermal infrared band

Sensor Wavelengths (μm)	Primary Uses
0.45 - 0.52	Coastal water mapping soil vegetation differentiation deciduous coniferous differentiation
0.52 - 0.60	Green reflectance by healthy vegetation
0.63 - 0.69	Chlorophyll absorption for plant species differentiation
0.76 - 0.90	Biomass surveys. water body delineation
1.55 - 1.75	Vegetation moisture measurement
10.40 - 12.50	Plant heat stress management. other thermal mapping
2.08 - 2.35	Hydrothermal mapping

DIRECT BROADCAST: Broadcasts are provided for ground stations which have entered into formal agreements covering the receipt and distribution of these data gathering Earth resources data. The digital format, wide spatial coverage, and repeatability of the data make possible new applications that could eventually increase the value of the information these data provide. By the late 1970's, some observers postulated that the data might eventually have sufficient commercial value to attract private investment in a remote-sensing system. However, it was also clear that barriers of high cost, and technological and economic risk would have to be drastically reduced to interest private investors in providing a system comparable to the Landsat system.

Transfer of space-based land remote sensing to private hands was first considered seriously in the drafting of President Carter's 1979 policy statement on space, PD/NSC-54, which amplified the earlier policy statements, PD/NSC-37 and PD/NSC-42. According to the President's Policy Directive, "Our goal is the eventual operation by the private sector of our civil land remote-sensing activities. Commerce will budget for further work in FY 1981 to seek ways to enhance private sector opportunities."[5] This statement left open the speed and the means of the transfer but, because it also committed the United States to provide continuity of the data flow from the Landsat system through the 1980's, most observers assumed that transfer to the private sector would take place about 1990. The first stage of that process was to transfer responsibility for operational management of the Landsat program to NOAA. Transfer of the meteorological satellite systems to private ownership was not envisioned by PD-54.

The Reagan administration decided early in its tenure to hasten the process of transfer, and announced "the intent of transferring the responsibility [of Landsat] to the private sector as soon as possible."[6] That statement, too, made no mention of the meteorological systems. Later, in March 1983, the administration proposed to transfer both the Landsat and the metsat systems to private hands.[7] The Department of Commerce commissioned three studies to explore and examine the issues raised by transfer of remote sensing from space to the private sector.[8] Significantly, none of these reports concluded that rapid transfer was in the best interests of the United States.

In November 1983, Congress passed appropriations bill H.R. 3222, which contained a provision preventing sale of the Nation's meteorological satellite systems to private hands. President Reagan subsequently signed that bill into law (Public Law 98-166). The meteorological satellites will continue to be operated as a public service. On January 3, 1984, the Department of Commerce released a request for proposal (RFP) designed to solicit offers from private industry to own and operate the Landsat and any follow-on system. Proposals are due on March 19, 1984.

The eventual goal of the transfer of the results of Government R&D to the private sector is to create ultimately a self-sustaining business from all or part of the technology so transferred, with the private firm in full control (except for appropriate regulation) of further development and shaping of the system and products. Realization of such a goal would constitute full commercialization of the Government-developed technology. Intermediate steps along the way to this end could result in: 1) shared control of the technology; and/or 2) joint continued development of the technology and its products, through either subsidies, shared investment, or guaranteed Government purchase. The process of transferring to such an intermediate step, in which the system would receive significant Government subsidy, has often been called "privatization."

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[5] "Presidential Directive NSC-54," Nov. 16, 1979.

[6] Statement of Joseph Wright, Deputy Secretary, Department of Commerce, to the Subcommittee on Space Science and Applications of the House Committee on Science and Technology, and the Subcommittee on Science, Technology, and Space of the Senate Committee on Commerce, Science, and Transportation, July 22 and 23, 1981.

[7] Statement of Malcolm Baldrige, Secretary of Commerce, to the Subcommittee on Natural Resources, Agricultural Research, and Environment of the House Committee on Science and Technology, Apr. 14, 1983.

[8] "Space Remote Sensing and the Private Sector: An Essay," National Academy of Public Administration, March 1983, Department of Commerce contract No. NA-83-SAC-066; "Commercialization of the Land Remote Sensing System: An Examination of Mechanisms and Issues," ECON, Inc., April 1983, Department of Commerce contract No. NA-83-SAC-00658; "A Study to Examine the Mechanisms to Carry Out the Transfer of Civil Land Remote Sensing Systems to the Private Sector," Earth Satellite Corp. and Abt Associates, Inc., Department of Commerce contract No. NA-83-SAC-00679.

Depending on the terms and conditions agreed on, transfer of the Landsat system to the private sector could result in any one of several outcomes. As OTA recently testified:

> Three principal alternatives seem plausible:
>
> - **Government contract** with one or more firms, either to provide a direct subsidy or to purchase data at an agreed-upon high price;
> - a **laissez-faire approach** with competitive bidding to supply data for Government needs; and
> - a **mixed, phased strategy** that would allow private vendors to build a market over time while retaining partial Government ownership."[9]

Whether such transfer would produce a commercially workable self-supporting system would depend on the interest of the private sector and the development of the market for data and data products (i.e., information) that is needed to sustain it. It would also depend on a national and international legal/political/security environment that permits the enterprise to seek success. Most of the debate over transfer centers on ideological, rather than practical, issues. Ultimately only the direct experience of the private sector can answer whether a self-supporting business will be the result, or whether such a goal is, at least for the time being, not feasible.

FOREIGN REMOTE-SENSING SYSTEMS

As the debate over the fate of the Landsat system continues, it is well to remember that as the United States deliberates, other countries are planning and building their own systems between now and 1990. These systems, particularly for land and ocean, present competitive challenges as well as opportunities for creative cooperative agreements.

Meteorological Satellite Systems

European Space Agency (ESA)—Meteosat-2 (1981). This geostationary satellite provides raw imagery of European weather conditions to Europe as well as relaying processed imagery from U.S. geostationary weather satellites. An improved Meteosat is planned for launch in 1985.

India—Insat-1 (1982). This geostationary satellite provides both communications and limited meteorological data. Insat-1B, which replaced Insat-1, was launched successfully by space shuttle Mission 8 in August 1983.

Japan—Geostationary Meteorological Satellite, GMS-2. This was launched by Japan on a Japanese NII launcher in 1981 and is the second in a series of geostationary meteorological satellites. It has now failed and GMS-1 will be used until a third satellite, GMS-3, can replace it in August 1984.

Peoples Republic of China—The Chinese are working on a Sun-synchronous meteorological satellite whose launch date is presently uncertain.

U.S.S.R.—Meteor (4 satellites; a cluster of Meteor 2-7, 2-8, and 2-10, and a single newer version, 2-9). Meteor is a polar-orbiting satellite with sensors capable of determining global ice and snow cover in addition to sensing cloud cover. The Soviet Union currently plans to launch one geostationary meteorological satellite (1984), with visible and infrared sensors.

Land and Ocean Satellite Systems

Brazil—The Brazilians plan to launch a moderate-resolution land-sensing satellite in the late 1980's. Few details are available about this proposed satellite.

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[9] "Landsat and Land Remote-Sensing Policy," statement of Dr. John H. Gibbons, Director, Office of Technology Assessment, to the Subcommittee on Space Science and Applications and the Subcommittee on Natural Resources, Agricultural Research, and Environment of the House Committee on Science and Technology, June 21, 1983.

Canada—Radarsat (1990). This satellite will provide C-band Radar images of Earth to monitor the polar sea ice; other sensors are in the planning stages.

European Space Agency—Remote Sensing Satellite (ERS-1)—(1987/88). It is planned primarily for passive sensing of the coastal oceans and weather over the oceans. It will also carry a synthetic aperture radar for active sensing of land through cloud cover.

France—SPOT (1985). A land remote-sensing satellite capable of high-resolution, multispectral (3 band) stereo images. It will be the world's first commercial* remote-sensing satellite system.

West Germany—Modular Optoelectronic Multispectral Scanner (MOMS)—(1984/85). This instrument was flown on the Shuttle Pallet Satellite (SPAS) developed by Messerschmitt-Boelkow-Blohm GmbH (MBB) aboard shuttle flight 7. MBB has entered into an agreement with COMSAT, and with the Stenbeck Reassurance Co., Inc., to market land remote-sensing data collected on shuttle flights beginning in 1984 if agreement with NASA can be reached. The West Germans also tested a limited synthetic aperture radar aboard Spacelab on shuttle flight 9.

India—IRS-1A (1986). A low-resolution "semi-operational" land remote-sensing satellite to be built in India and launched by a Soviet launcher. A follow-on, IRS-1B, will be launched by an Indian-built launcher.

Japan—Marine Observation Satellite-1 (MOS-1)—(1986) and Japan Earth Resources Satellite-1 (JERS-1)—(1990). MOS-1 is being developed primarily for sensing various parameters of the ocean. It will also be useful for land remote sensing. JERS-1 is primarily a land remote-sensing satellite carrying a synthetic aperture radar that will also have some limited marine uses.

U.S.S.R.—Meteor Priroda (1980); Kosmos 1484 (1983). Both are experimental land remote-sensing satellites with low (170 m), moderate (80 m), and high (30 m) resolution electronic and mechanical scan sensors that operate in a variety of wavelengths. The Soviets consider the later satellite superior to Landsat 4, and have offered data from them to the Eastern bloc as well as the developing countries.

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*Although the SPOT system is organized as a commercial system, it is, for the time being, heavily subsidized by the French Government.

THIS TECHNICAL MEMORANDUM

The goal of the analysis of each of the following chapters is to present Congress with potential requirements the Government might wish to impose on private industry in supplying meteorological and land remote-sensing data. The third chapter, *International Relations and Foreign Policy*, describes the current international policy and practice of the United States in remote sensing from space and explores its international obligations as defined by treaties and agreements. It also examines the utility of remote-sensing data derived from space as an element of U.S. foreign policy, social and diplomatic outreach. The chapter explains requirements now demanded by law, and discusses other possible conditions that might be imposed for the specific benefit of the United States. Finally, the third chapter discusses the worries other countries have expressed about private ownership of U.S. remote-sensing systems.

Chapter 4, *Public Interest in Remote Sensing*, includes a short discussion of the civilian public good aspects of remote sensing as well as tables of uses of remote-sensing data by domestic and foreign non-Federal users. Short case studies show how State and local governments, private industry, and research and educational institutions integrate remote-sensing data into other information needs.

Chapter 5, *U.S. Government Needs for Remote-Sensing Data,* summarizes projected future Federal needs for remote-sensing data, and shows where land remote-sensing data have been used to satisfy the requirements of congressionally mandated studies. A section of this chapter analyzes the sales of Landsat data.

Chapter 6, *National Security Needs and Issues* analyzes the national security aspects of civilian remote sensing and discusses the feasibility of having private industry supply the data needs of the military and intelligence communities.

Preparation of the Technical Memorandum

In preparing this technical memorandum, OTA relied on personal interviews, contract studies from several individuals, and the results of two OTA workshops. In the first workshop, held July 26, 1983, participants drawn primarily from the private sector discussed those broad issues implicit in the transfer of remote-sensing systems related to international trade, foreign policy use of remote-sensing data, public-good aspects of land and meteorological remote sensing, and finally, national security issues. The second workshop, composed solely of participants from the executive agencies, discussed most of the same issues from the standpoint of Government policy and plans.

Throughout our discussions it was extremely difficult to separate the question of whether this country will continue to operate a land remote-sensing system from the question of what conditions and requirements a private firm should meet. **Customers of the data fear that the entire ability to gather and distribute useful land remote-sensing data might well be lost in the debate over transfer. They argue that uncertainties over the fate of land remote sensing have impeded the growth of a market for data and, consequently, the development of a strong value-added industry.**

OTA is grateful to the workshop participants and to the many others who provided information or reviewed portions of the draft of this technical memorandum. Their helpful and timely comments and suggestions made it possible to complete this report expeditiously.

Chapter 3

International Relations and Foreign Policy

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Chapter 3

International Relations and Foreign Policy

Among the most important and difficult issues to resolve in transferring civilian remote-sensing systems to the private sector are those related to international relations, international trade, and foreign policy. Data products from both the civilian meteorological and land remote-sensing systems have been and remain important instruments of U.S. foreign policy. These data and the technologies from which they spring remind other countries of U.S. leadership in space technology and U.S. dedication to using space for "the benefit of all mankind."[1] Their use in numerous developing countries has allowed the United States to share its technological expertise and create good will for U.S. interests without transferring critical aspects of U.S. technology. In addition, data from these satellites have raised the level of awareness of major environmental problems throughout the world. By providing a means for self-directed resources management, remote-sensing systems help to create self-sufficient allies rather than technological dependents.

Although many countries accept the use of U.S. remote-sensing systems, some have also questioned the right of the United States to sense their countries or to sell sensed data to third parties, and have argued that limits should be placed on the sensors' ground resolution. In addition, some countries that have accepted a U.S. Government-owned system have articulated deep concerns about the potential for abuse of data generated and marketed by privately operated systems.

Transfer of the metsat or Landsat systems to the private sector would likely affect U.S. relationships with the world community. Examination of the Landsat system's importance to international relationships, including trade, reveals that transfer of the active system would strongly affect foreign as well as domestic users of the data.

This chapter identifies and discusses the major international issues connected with remote sensing as they relate to the transfer of the U.S. civilian systems to the private sector. It also suggests requirements that might be imposed on a private corporation seeking to own and operate remote-sensing systems.

THE INTERNATIONAL CHARACTER OF REMOTE SENSING FROM SPACE

Aircraft or balloons are clearly limited in overflight by national legal restrictions on sovereign airspace, but spacecraft have no overflight restrictions. According to international treaty, "Outer space and celestial bodies are not subject to appropriation by claim of sovereignty, by means of use or occupation, or by any other means."[2] This principle is understood by the United States and most other nations to mean that nations are free to place in orbit any satellite that does not violate other provisions of the 1967 Outer Space Treaty.

This understanding has been called the "open skies" principle; it is a fundamental principle of the U.S. space program. The United States supports it in part by insisting on making civilian remote-sensing data available on a nondiscriminatory basis to anyone who wishes to receive them. Meteorological data are available free of charge to any country or organization capable of receiving the signals; land remote-sensing data are sold at uniform prices on an equal, nondiscriminatory basis.

The United States, through the U.S. Agency for International Development (AID), the U.S. National Oceanic and Atmospheric Administration (NOAA), and the international World Meteorological Organization (WMO), has been successful in helping some 125 countries and organizations purchase appropriate receiving terminals to receive meteorological data from U.S. satellites (see table 1). For some of the poorest countries, such stations are their only means of gathering synoptic weather data to warn of potentially destructive storms or dramatic climatic changes. In

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[1] National Aeronautics and Space Act (NAS) of 1958, sec. 102 (a).

[2] "Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies," Oct. 10, 1967: art. II.

Table 1.—Countries With APT/HRPT Reception Capabilities

Countries with APT facilities:

Afghanistan
Algeria
Angola (status unknown)
Antarctica (USN res.)
Argentina
Australia
Austria
Azores
Bahamas
Bahrain
Bangladesh
Barbados
Belgium
Bermuda
Bolivia
Brazil
Bulgaria
Burma
Cambodia (status unknown)
Cameroon
Canada
Canary Islands
China (Mainland)
China (Taiwan)
Chile
Colombia
Costa Rica
Curacao
Czechoslovakia
Denmark
Dominican Republic
Ecuador
Egypt
El Salvador
Ethiopia
Fiji
Finland
France
French Guiana
Gambia
German Democratic Republic
Germany, Federal Republic of
Ghana
Greece
Guatemala
Guadeloupe
Guyana
Honduras
Hong Kong
Hungary
Iceland
India
Indonesia
Iran
Iraq
Italy
Israel
Ivory Coast
Japan
Jordan
Kenya
Korea
Kuwait
Madagascar
Malaysia
Mali
Malta
Martinique
Mauritania
Mauritius
Mexico
Mongolia
Morocco
Mozambique
Nepal
Netherlands
Netherlands Antilles
New Guinea
New Zealand
Nicaragua
Nigeria
Norway
Oman
Pakistan
Paraguay
Peru
Philippines
Poland
Portugal
Romania
Saudi Arabia
Senegal
Seychelles
Sierra Leone
Singapore
Somalia
South Africa
South Yemen
Spain
Sri Lanka
Sudan
Surinam
Sweden
Switzerland
Syria
Tahiti
Tanzania
Thailand
Trinidad and Tobago
Tunisia
Turkey
Union of Soviet Socialist Republics
United Arab Emirates
United Kingdom
United States
Upper Volta
Uruguay
Venezuela
Viet-Nam, Republic of (status unknown)
Yugoslavia
Zaire
Zambia
Zimbabwe

Countries with HRPT facilities:

Belgium
Brazil
Canada
China (Mainland)
Czechoslovakia
Federal Republic of Germany
France
Greenland (Denmark)
India
Indonesia
Iran
New Zealand
Norway
Saudi Arabia
Sweden
Union of Soviet Socialist Republics
United Kingdom
United States
Yemen (South)

SOURCE: National Oceanic and Atmospheric Administration.

return, these countries provide the United States with their local weather data which are crucial to both U.S. civilian and military users.

As the National Aeronautics and Space Administration (NASA) developed the Landsat system, it encouraged use of the system by other countries. Ten countries now own Landsat receiving stations. In return for a fee, these foreign stations receive Landsat data sensed over their region and sell or distribute data to domestic and foreign customers. Further, through AID and NASA, the United States has been a principal force in setting up foreign regional and national centers capable of processing and interpreting Landsat data. By integrating these data with meteorological, aircraft, and ground data of all kinds, these centers help developing countries to cope with the enormous problems of environmental protection and resource management, particularly in isolated, rural areas.

WMO is a specialized agency of the United Nations (U.N.), the purpose of which is to coordinate, standardize, and improve meteorological services throughout the world. It consists of more than 150 member countries and territories, each of which maintains its own meteorological service. Established under a 1947 convention, WMO has fostered international cooperation in meteorology through such programs as the World Weather Watch, a system for comprehensive global weather observation, and through the Global Telecommunications System for global exchange of meteorological data (fig. 1). The WMO convention itself imposes no obligation for data exchange, but the free interchange of meteorological data from terrestrial stations and satellites has become an established custom of great utility to the participating countries.

Satellites from several countries provide data for this exchange. The Geostationary Meteorological Satellite (GMS-Japan), Meteosat (operated by EUMETSAT and the European Space Agency), and most recently the INSAT (India) geostationary satellites provide visible and infrared imagery, data communications systems and weather facsimile (WEFAX) charts.* These satellites, plus the U.S. satellites and the planned Soviet geostationary satellite, make up the heart of the World Weather Watch of the WMO.

***INSAT does not furnish WEFAX transmissions.**

INTERNATIONAL RELATIONS AND FOREIGN POLICY AIMS

A recent administration report acknowledges that if the United States transfers its Landsat system to the private sector, it must consider the effect this step will have on a wide range of U.S. interests:

> In remote sensing the readily available products of United States meteorological and land satellites are used routinely by the world community. The result has been a large measure of good will and support of our positions in the U.N. and other international fora.[3]

As this passage indicates, in serving the international community, data products from the U.S. remote-sensing systems have been important instruments of U.S. foreign policy. Not only have these data aided other countries in predicting harmful weather patterns and in managing and exploiting their own resources, they have served to raise the general level of awareness of growing environmental problems throughout the world. The data from the metsat and Landsat systems have also provided the United States influence in some countries that strongly disagree with us on certain international political issues. In such developing countries as Thailand, Bangladesh and

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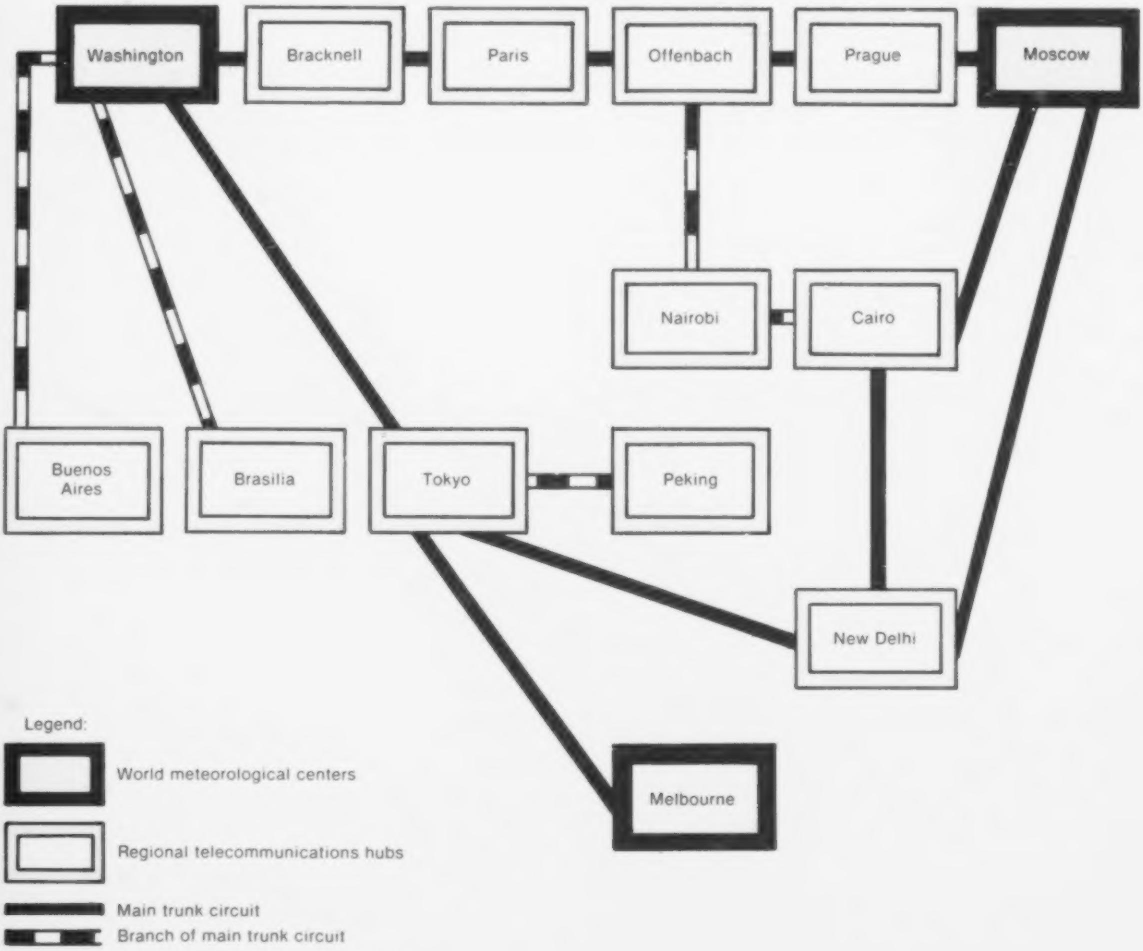
[3] The President's Report to Congress on Science, Technology, and American Diplomacy for Fiscal Year 1982.

Figure 1.—Diagram of the Global Telecommunications System


Washington
Bracknell
Paris
Offenbach
Prague
Moscow
Nairobi
Cairo
Buenos Aires
Brasilia
Tokyo
Peking
New Delhi
Melbourne
Legend:
World meteorological centers
Regional telecommunications hubs
Main trunk circuit
Branch of main trunk circuit

SOURCE: National Oceanic and Atmospheric Administration.

Kenya, the desire to use remote-sensing data from U.S. satellites has even effected changes in political and institutional structures (see section on "Developing Countries" in this chapter and app. A). The metsat and Landsat systems also remind other countries of U.S. leadership in space technology.

Primarily through the Landsat system, the United States has been able to overcome potential foreign opposition to satellite remote sensing for national security as well as civilian uses, and to offset repeated attempts by the Soviet bloc to impose regimes whose intent is to restrict the free flow of information. Indeed, the Landsat program can be considered to be a cornerstone of the U.S. "open skies" policy and of its policy on the use of space for "peaceful purposes for the benefit of all mankind."[4] By making data from the Landsat system available to all potential purchasers on a nondiscriminatory basis, the United States has been able effectively to blunt criticism that might otherwise have resulted from its extensive use of military reconnaissance and other satellites. Moreover, the open availability of Landsat data to anyone regardless of nationality or political persuasion is a powerful message to governments op-

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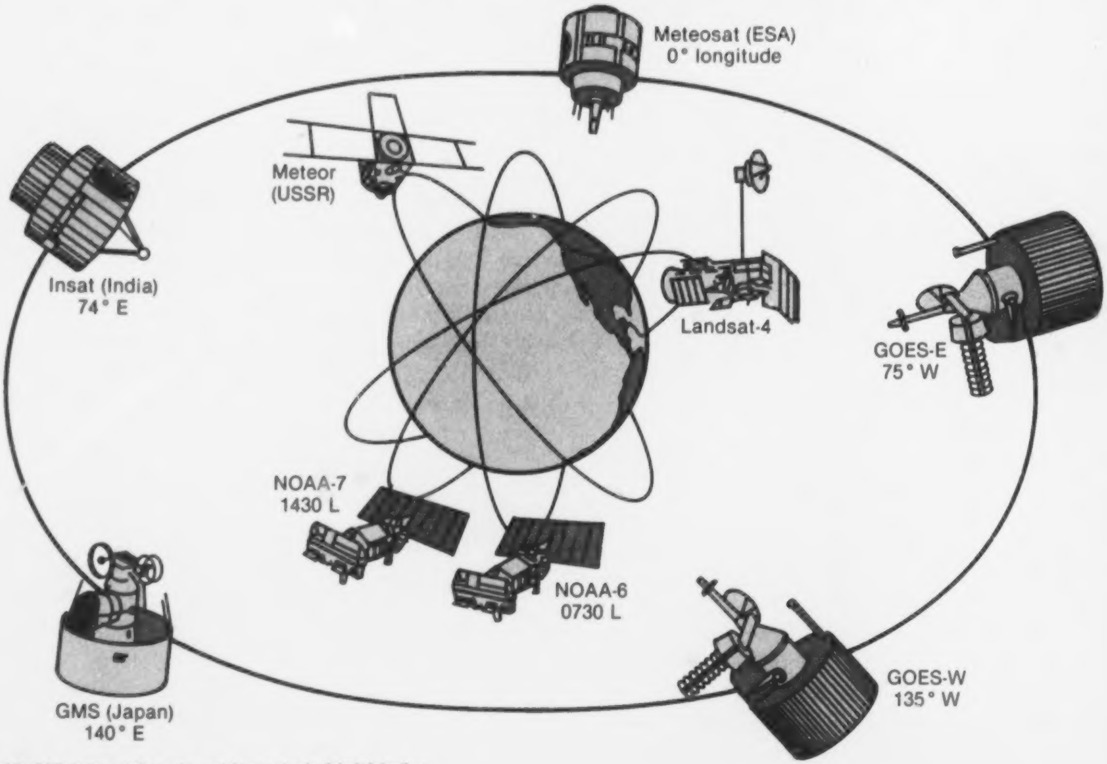
[4] NAS Act of 1958, op. cit.

Operational Earth Observation Satellites



SOURCE: National Oceanic and Atmospheric Administration.

posed to the open interchange of ideas and information.

The following discusses several areas critical to foreign policy and international relations that any planning for the future treatment of land and meteorological remote-sensing satellite systems must address.

Meteorological Remote Sensing

Data Distribution Policy

As noted in the previous section, the U.S. policy on meteorological data conforms to the global practice of distributing such data freely and at no cost to the other countries of the world. Tentative suggestions by U.S. officials that the United States might begin to charge other nations for these data were met with warnings that the United States was tampering with well-established, long-term data practices and that other countries might reciprocate.

In addition, two of the instruments carried on U.S. metsats are provided by other countries. The United Kingdom, through the British Meteorological Office, has provided the Stratospheric Sounding Unit for the U.S. TIROS-N polar orbiter. In a tripartite agreement among NOAA, NASA, and the French Centre National D'Etude Spatiales (CNES), the French provide and operate the ARGOS data collection system for the NOAA polar orbiter. These arrangements help reduce NOAA's costs and make the polar-orbiting satellites much more capable than they would be otherwise.

Because the United States receives more data through WMO than it supplies to the rest of the world, charging for metsat data would result in a net cost to the United States. In part because of the negative response from other countries and in part because of the outcry from U.S. users of foreign data as well as Congress,[5] the administration subsequently reaffirmed its commitment to supplying meteorological data freely and free of charge.

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[5] House Concurrent Resolution 168, Sept. 19, 1983; Senate Concurrent Resolution 67, Sept. 19, 1983: 98th Cong., 1st sess.

Value-Added Services

Value is added to meteorological data when they are used by specialized firms to predict severe impending weather for the benefit of specialized groups, such as regional farmers or the international shipping industry. Value-added firms and Government organizations are also learning how to process meteorological data conjointly with land remote-sensing data to predict crop yields, both domestically and abroad (see ch. 4).

A private operator would likely be interested in entering the value-added business, since outside the Government, there would be only a modest market for unprocessed data. Unlike the case of land remote sensing (discussed below), where the primary economic value of the data can only be realized after sophisticated and expensive data processing, the primary economic value of the data from the meteorological satellites is in their ability to warn of impending severe or unusual weather. Receiving terminals and the necessary data-processing equipment for obtaining basic meteorological data are relatively inexpensive; most countries and many smaller economic entities can afford to purchase and operate them. Thus, for meteorological data, no apparent conflict would exist in allowing the data supplier to sell value-added services, as long as the raw data remain freely available to everyone with the capacity to receive them.

Continued Applied Research

Although the meteorological satellites have been in operational use for nearly two decades, there is a continuing need to refine the observations they make, and to learn to integrate these observations with other land, ocean, and atmospheric data in order to make them more generally useful.

When the National Weather Service first assumed responsibility for operating the meteorological satellites, NASA was charged with continuing the research and development for new meteorological sensors and satellites. This work resulted in substantial improvements in the polar-orbiting satellites, and in the development of the geostationary meteorological satellites (GOES). However, in recent years the NASA R&D program for new satellites and sensors (the Nimbus series of experimental meteorological satellites) has diminished nearly to zero, and for budgetary reasons, NOAA has not been able to take up where NASA left off. Consequently, little hardware research is now being carried out in the civilian programs. In addition, military research on sensors has slowed considerably for lack of suitable civilian satellites to attach them to. Prior to the demise of the Nimbus program, NASA, NOAA, and the Department of Defense (DOD) used these satellites to test new sensors and techniques.

U.S. meteorological satellites have demonstrated U.S. leadership in this technology. If the United States is to continue to lead, it will be important to continue research in sensors, satellites, and other hardware development.

The Government has continuing research programs to utilize meteorological data to best advantage, both for short- and intermediate-term weather forecasting and for climate research. Much of this research is conducted in collaboration with industrialized and developing countries. Since receiving and processing meteorological data from satellites provide an excellent way to learn about and use space technology, it would be in the long-term best interests of the United States to continue applications research projects with both industrialized and developing countries. It will be especially useful to find new ways to integrate these data with ocean and land satellite data. Such work would most usefully be carried out in conjunction with private industry.

Land Remote Sensing

Data Sales and Foreign Policy

Because the U.S. space program and U.S. foreign policy have benefited from the policy of nondiscriminatory sale of Landsat data, this policy assumes importance in foreign relations. If the proposed transfer is made, the private firm will want to set its own data policies. In general, commercial interests want private ownership of data and the ability to copyright them so data can be sold profitably. Thus, a commercial venture is likely to require proprietary rights in distributing data in order to gain or maintain economic advantage over possible competitors. However, this is contrary to notions of open access to information for the public good. Indeed, the Department of Commerce's Source Evaluation Board has recognized the interests of the private sector and the difficulties of the embryonic market for data in its Request for Proposals (RFP), in which it states simply:

> (1) Conform his [the owner's] Earth remote-sensing programs as closely as is commercially possible to traditional U.S. Government practices of providing civil land remote sensing satellite data to all users on an open, equal, nondiscriminatory basis; (2) Consult with and obtain the approval of the U.S. Government before instituting major changes in international data distribution practices, to ensure that such changes are in conformity with the international obligations and foreign policy objectives of the U.S.[6]

The question is whether it is in fact "commercially possible" to maintain the policy the United States has fought so hard to maintain in the United Nations and other international bodies. The formulation of the RFP would leave the matter largely up to private interests to decide. **In view of the continued importance of the "open skies" principle to the U.S. use of space, it will be important for Congress to consider carefully the implications of this potentially radical change of policy.**

Value-Added Services

Most of the profit from the use of land remote-sensing data will be gained by those corporations that enhance Landsat data to improve their usefulness (the so-called value-added industry). These companies integrate Landsat data with other information to make powerful analytical and predictive commercial products. They constitute a small, but growing, industry.

There can be little doubt that a private owner of the Landsat system would want to enter into the value-added business. The Source Evaluation Board's RFP proposes to allow the system's owner to process the primary data and to package those data in whatever ways it sees fit, including offering a variety of value-added products, as long as Federal data needs are met.[7]

However, many developing countries have expressed the fear that if the company owning the collection and distribution system were also allowed to offer value-added services, it might take special advantage of having control over the distribution process (i.e., a monopoly position) to gain economic leverage over countries that do not have the facilities or personnel to process and interpret the data themselves. For example, a company might delay distribution of data to a sensed country until after the company had a chance to exploit the data itself for resource information. From the standpoint of international relations, it may be appropriate for the United States to restrict the private owner from entering into the value-added business. At the least, the private owner would have to be closely regulated to see that unfair economic leverage was not applied over other countries or over other value-added corporations.

If the market for land remote-sensing services grows to the point that competitive, timely, data services are available, thereby limiting the power of one company to exert such unfair leverage, any restrictions could be relaxed because competition would make value-added services more readily available. A possible alternative strategy, but one that would be unlikely to gain the support of private companies, would be to require data analysis to be sold openly as well.

U.S. Technological Leadership in Cooperative Projects

During the decade that the Landsat system has existed, the United States has encouraged both industrialized and developing countries to participate in generating applications for Landsat data (i.e., applied research). That this approach has been successful is demonstrated by the fact that

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[6] "Request for Proposals for Transfer of the United States Land Remote Sensing Program to the Private Sector," U.S. Department of Commerce, Jan. 3, 1984, VII. 6-3.

[7] Ibid., p. ii.

10 countries now own Landsat receiving stations and pay a yearly fee of $600,000 to the U.S. Government to receive data. Although the stations are owned and operated by the host country and some of the equipment is manufactured outside the United States, the receiving stations clearly demonstrate U.S. leadership in developing and transferring high technology.

The United States has also benefited directly from helping to establish these receiving stations, for they have provided critical foreign multispectral scanner (MSS) data for U.S. Government projects, both domestic and bilateral. Without these foreign resources, worth millions of dollars, the success of the Landsat program would have been severely limited. Some companies have found data from foreign ground stations to be crucial in their business. Thus, they benefit from existing bilateral agreements with foreign ground stations and from the exposure of a wide variety of potential data users to Landsat data products.

It is critical for the United States to maintain its cooperative basic and applied research programs in remote-sensing technology with other countries, both to advance U.S. research objectives and to retain U.S. leadership in the technology of outer space. Without help from the Government, a private owner is unlikely to have the resources or the inclination to pursue research with other countries. Still, private industry has a significant role to play in applications demonstrations.

INTERNATIONAL OBLIGATIONS: TREATIES AND AGREEMENTS

The United States is a party to four major international agreements formulated by the U.N. Committee on the Peaceful Uses of Outer Space (COPUOS) that may affect the operations of private Earth resources remote-sensing systems:

- **Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies (1967).** Among other things, the treaty defines the principles for the exploration and use of outer space and holds States responsible for the space activities of their citizens.
- **Agreement on the Rescue of Astronauts, the Return of Astronauts, and the Return of Objects Launched Into Outer Space (1968).** This agreement provides for the rescue and return of downed or stranded astronauts as well as the return of a space object and "its component parts." It specifies that "the State responsible for launching" shall pay the expenses for recovering and returning the space object or its parts.
- **Convention on International Liability for Damage Caused by Space Objects (1972).** This convention is an extension of articles VI and VII of the 1967 treaty. It defines "damage" as loss of life, personal injury, impairment of health, loss or damage to property or persons or property of international organizations. "Launching" is held to include attempted launching and a "launching State" is one that either launches or procures the launch of a space object. It is also one "from whose territory or facility a space object is launched."
- **Convention on Registration of Objects Launched Into Outer Space (1974).** The information registered includes the name of the launching State or States, an appropriate designator or a registration number, the date and territory of the launching, the initial basic orbital parameters including the nodal period, inclination, apogee, perigee, and the general function of the space object.

Of particular importance to potential private operators of remote-sensing satellite systems or any other space system, is the 1967 **Outer Space Treaty.** Article VI of this treaty states: "The activities of non-governmental entities in space . . . shall require authorization and continuing supervision by the appropriate State party to the treaty." Although the terms "authorization" and "continuing supervision" have been interpreted differently, article VI clearly requires some form of licensing and adherence to Government-imposed regulations.

Similarly, article II of the 1972 **Liability Convention** makes the launching State responsible for personal and property damage caused by any satellites or launchers even if they are no longer under the operation or direct control of the Government. At a minimum, the Government would require assurance that the owner of the satellite system had purchased adequate insurance to cover possible damages.

The U.S. Government has not yet decided on the precise mechanisms of ensuring that private corporations comply with international treaty obligations. Given the importance of this technology to U.S. foreign affairs, it is clear that the Department of State must play a major role.

The Role of the Department of State

In general, private operation of the U.S. remote-sensing systems may lessen the potential for using them as a tool of U.S. foreign policy. Transfer to the private sector could also diminish the accountability of remote-sensing operations to international law and public opinion by removing them from direct public control. The Department of State therefore should have two primary concerns: 1) to ensure that a private owner meets all the international obligations of the United States; and 2) to see that its activities support, or at the least do not interfere with, other U.S. diplomatic interests.

The Department of State would have to assure a private operator's adherence to the provisions of the various U.N. treaties on space discussed above. The specific regulatory mechanisms it would use and the penalties to be imposed for noncompliance are presently undefined. The Department's function in assuring that the activities of a private corporation support U.S. diplomatic interests is important, but difficult to execute because the Department would have to work directly and continuously with the private sector. Such a role would require the Department to assess the past benefits of Government remote-sensing activities and determine which of these should be retained in the future. The private company, on its own, cannot be expected to understand and comply with U.S. foreign policy objectives.

In this process, it would be important to distinguish between those benefits which do not outweigh the advantages of private sector operation and those which are essential to U.S. interests. The essential benefits must somehow be preserved by the transfer agreement. **The State Department should examine closely the degree to which past remote-sensing projects have aided U.S. efforts at the U.N. and other international forums dealing with all issues related to outer space, then establish the means to continue to use this technology in the service of U.S. foreign policy and international relations.**

In regulating a private land remote-sensing system the Department of State and other Federal agencies (e.g., the Department of Commerce), would be breaking new ground. They therefore have an opportunity to develop imaginative strategies for dealing with the private sector. These strategies are particularly important because they would deal with a technology which, because of its economic implications (i.e., the data can be used to help in exploring for the resources of countries), raises the political sensitivities of other countries. Some countries worry they will lose control over resources under their sovereign control.

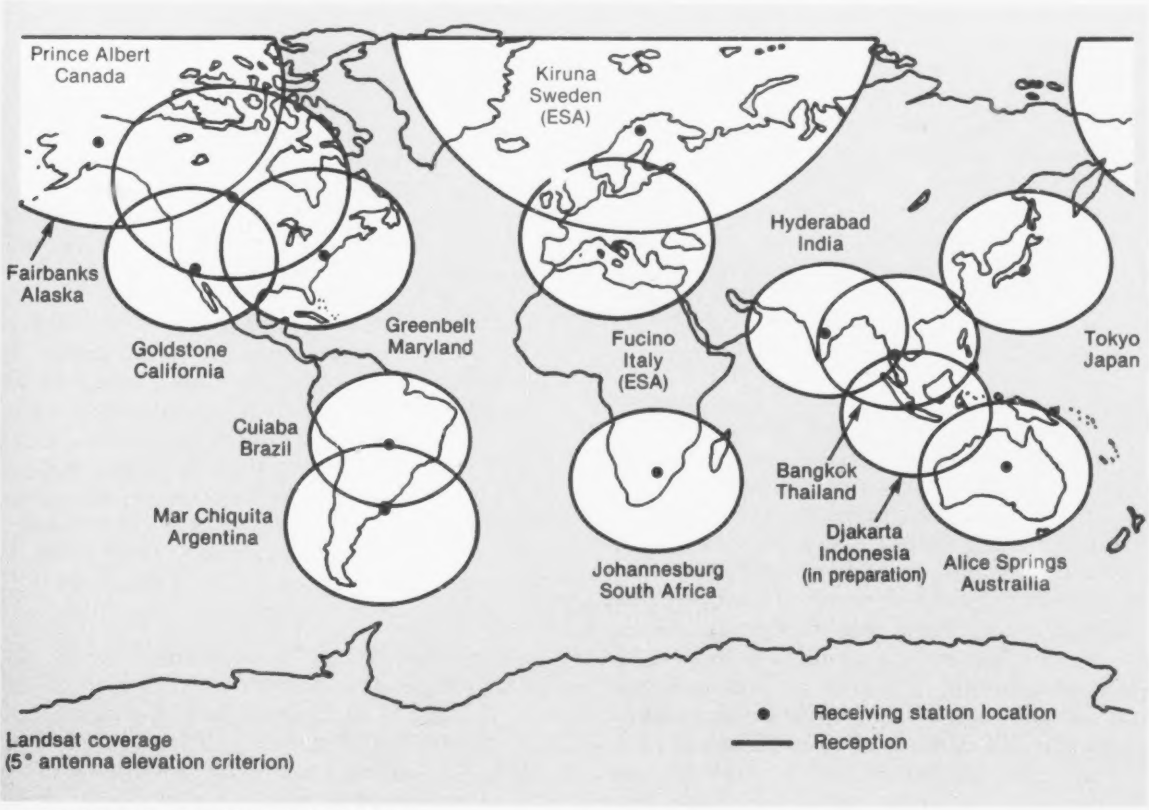
One possible mechanism would be to establish a permanent private sector advisory group to work with the Department of State to advise on ground rules for international operation of the system. Nevertheless, the Bureau of Oceans and International Environmental and Scientific Affairs (OES) of the Department of State, which would likely be charged with this responsibility, would have to strengthen its expertise in space technology and its commitment to using space technology as part of the outreach of the United States.

In the past, NASA has taken the lead in establishing cooperative ventures with other countries; it will continue to do so for most space projects. One reason NASA has been so successful is that it is well based in the technology and has carefully chosen projects that directly served the best interests of NASA.[8] The Department of State has never had a strong interest in cooperative programs in space technology,[9] in part because space technology constitutes only a very small part of its total mission. Yet, as private sector involvement in space grows, the Department will be in the difficult position of mediating between U.S. private companies, which would want as few restrictions as possible, and foreign countries which might want strong restrictions. The Department might have to choose between making friends and influencing nations abroad and rallying domestic support.

Relationship of Private Sector to Foreign Ground Stations

The foreign ground stations are all government-owned and government-operated and receive data from the Landsat satellite by agreement with the U.S. Government. Each station is now required to pay $600,000 per year for the right to receive and distribute or sell MSS data from the satellite. Before fiscal year 1983, the charge was $200,000. According to the terms of the Memoranda of Understanding between NOAA and these governments, the stations may receive and preprocess these data and sell them to their

Distribution by Foreign Ground Stations (as of Jan. 1, 1984)


Prince Albert
Canada
Kiruna
Sweden
(ESA)
Hyderabad
India
Fairbanks
Alaska
Greenbelt
Maryland
Goldstone
California
Fucino
Italy
(ESA)
Tokyo
Japan
Cuiaba
Brazil
Bangkok
Thailand
Mar Chiquita
Argentina
Djakarta
Indonesia
(in preparation)
Johannesburg
South Africa
Alice Springs
Austrailia
● Receiving station location
Reception
Landsat coverage
(5° antenna elevation criterion)

SOURCE: National Oceanic and Atmospheric Administration.

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[8] *UNISPACE '82: A Context for International Cooperation and Competition—A Technical Memorandum* (Washington, D.C.: U.S. Congress, Office of Technology Assessment, OTA-TM-ISC-26, March 1983), app. B.

[9] T. K. Glennan, "Technology and Foreign Affairs, A Report to Deputy Secretary of State Charles W. Robinson," December 1976, p. 33; Norman A. Graham, Richard L. Kauffman, and Michael C. Oppenheimer, "A Handbook for U.S. Participants in Multilateral Diplomacy: The U.S. and U.N. Global Conferences," report prepared for the Department of State by the Futures Group, September 1981, p. 15.

customers. In return, they agree to abide by the same nondiscriminatory sales policy practiced by the United States. If the private owners of the remote-sensing systems are permitted to pursue discriminatory data policies, the United States will lose its leverage over operations and data product distribution policy of the foreign ground stations.

Future International Coordination

The United States currently participates in the deliberations of the Landsat Ground Station Operators Working Group and the Coordination on Land Observing Satellites, organizations which coordinate standards for land remote-sensing systems. With transfer of the land remote-sensing satellite system to private ownership, it would be important to spell out how private firms would have to interact with the agencies that represent the United States in these organizations.*

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*It is not clear that the Government would still have a role to play in the Landsat Ground Station Operators Working Group upon transfer of the system to private hands.

DEVELOPING COUNTRIES

Landsat and metsat technology, and U.S. programs through AID, NASA, and NOAA to transfer data-processing technology to developing countries, have affected the institutional structure of developing countries, and the manner in which the countries treat environmental problems. These programs have also affected their relations with the United States.*

In the developing world, AID and NASA have been the principal agents in setting up regional and national centers capable of collecting, processing, and interpreting Landsat data and combining them with other data. The resulting information has helped developing countries to cope with the enormous human and physical problems of resource management, particularly in isolated areas. The United States has shown the rest of the world how to use Landsat data as a powerful tool for attacking such serious global environmental problems as deforestation and desertification, problems that respect no political boundaries.

In short, in helping to solve these pressing problems, satellite remote sensing has made a distinctive contribution to the international image of the United States as a leader in the effort to assess and protect global resources.

For the past 25 years the United States has stated in international gatherings that its exploration and research in space would be used for the benefit of all mankind. For the past 15 years, developing countries have been told that the current satellite remote-sensing system (Landsat) was experimental and that eventually an operational system would exist in the spirit of international cooperation that has been a hallmark of the U.S. civilian space program. In addition, in the face of strong international opposition, the United States has stood by its policy of open dissemination of data gathered by satellite. Now, as the administration moves toward transfer of the Landsat system to private hands, many observers question the effect the transfer proposal would have on the broader agenda of U.S. relations with the developing world and on past U.S. commitments.

Transfer of the Landsat system to the private sector would have some positive effects on the use of satellite data in developing countries (e.g., private firms should be able to offer more timely data and provide a greater variety of services than does the U.S. Government). Nonetheless, some of these countries see the transfer as another signal that the United States is reversing its longstanding policy for outer space and becoming less cooperative in space activities with developing countries.

Transfer of the Landsat system could well contribute to already deteriorating relations between the United States and developing countries in international forums and negotiations. U.S. policymakers should decide whether the goal of immediate private sector ownership and operation of remote-sensing systems is more important for political/economic principle and domestic budgetary reasons than long-term political relations between the United States and the developing world. A phased transfer or limited transfer could ease the political problems the United States might face.

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*See app. A for a more detailed treatment of this subject.

One reason AID and NASA have been able to promote the use of Landsat data in other countries is that the data have been readily available at very low prices (the greatest costs have been borne by NASA through its funding of the Landsat program). Such a policy is appropriate during research and development, when it is important to encourage many potential users to experiment with the data. However, now that the system has been declared operational and may be transferred to private ownership, the price for data must approach the costs of building and maintaining a system. There are other price and cost issues that must be resolved; for instance, will the United States continue to provide data for projects that draw "good will and support?" It will be increasingly difficult for AID and other agencies to provide data and other support for remote-sensing projects in an era of increasing costs and decreasing budgets. Yet U.S. mission agency technical programs have been largely responsible for the development and maintenance of the international community of users of data from Landsat. The small market for remote-sensing data that exists abroad today exists because of previous U.S. financial and technical assistance. Further, if such assistance were to stop after the technology was transferred to private ownership, it might re-ignite the international debate over ownership and dissemination of the data from remote-sensing satellite systems (see discussion in the following section).

We must also consider the costs to the United States of not continuing this aid to other countries. From the standpoint of developing markets for U.S. products, it is clearly in the best interests of the United States to continue to encourage other countries to become familiar with land remote-sensing data and their uses. **If the transfer to the private sector is made, it will therefore be important for Congress to assure that appropriate funding is continued for these worthy projects.**

INTERNATIONAL LEGAL ASPECTS OF REMOTE SENSING

Countries are well aware that the possession of satellite remotely sensed data and the ability to analyze them gives others power to affect their resource development. Data from the meteorological satellites are generally not in question because they are low resolution and are widely perceived by other countries to be of little use in exploiting a country's resources. Private ownership of the land remote-sensing system may heighten suspicions that such data would be used to enable interests outside the sensed country to gain a competitive advantage, or that information on crop conditions or military activities of States might be sold preferentially to political adversaries. The developing countries are particularly concerned about this issue, since many lack the indigenous ability to analyze the data.*

Some countries maintain that they should have priority access to data derived from the sensing of their territory, while others have argued that their consent should be obtained before these data are transferred to third parties. These states base their claims on the political-legal concept of national sovereignty over resources.

The United States has consistently opposed efforts to limit the distribution of Landsat data, arguing that remote sensing is a peaceful and beneficial use of space in which the constraints of national sovereignty have no valid application. Further, it has held that the free collection and dissemination of primary data and analyzed information is supported legally and encouraged by the 1967 Outer Space Treaty and article 19 of the U.N. Declaration of Human Rights.

Some countries carried this debate into the UNISPACE '82 conference, held in Vienna,

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*Their concerns over remote-sensing data are directly linked to similar concerns over *access* to information of all kinds as well as their ability to *use* it.

Austria, in August 1982. Mexico, on behalf of the Group of 77, submitted a position paper at the conference which stated:

> The Group of 77 believes that sensed states should have timely and unhindered access on a priority basis . . . to all data and information obtained over their territories. Dissemination of such data and information derived from it to a third party should not be done without the prior consent of the sensed country.[10]

This wording was rejected for the final UNISPACE '82 report, but the United States can expect similar attempts to restrict the sale of data in the future.

In future meetings of the U.N. Committee on the Peaceful Uses of Outer Space, the United States will have to defend any new policies with respect to private sector use of outer space. **Therefore, it will be extremely important that these policies be thoughtfully formulated and defensible in international forums.** Our previous strict policies of nondiscriminatory data sales and the free flow of information have served us well in deflecting many attempts to restrict the right to sense other countries and sell those data to third parties.

Should the Group of 77, or other concerned nations, obtain a consensus about the necessity of prior consent for remote-sensing activities, such a decision could negatively affect the private sector's ability to market data internationally. Although the decision would not bind the U.S. private firm to follow certain procedures, its existence could cause countries to place sanctions on U.S. remote-sensing products, or turn to other suppliers of data. More important, a "prior consent" regime could affect Government data acquisition programs.

INTERNATIONAL TRADE

As noted earlier, outside of limited distribution of land remote-sensing data by the Soviet Union, the United States has been the sole supplier of land remote-sensing data to the world. Yet today, while the United States deliberates over the appropriate disposition of the Landsat system, other countries are developing their own land and ocean remote-sensing systems. Canada, France, India, Japan, and the European Space Agency all plan to launch remote-sensing satellites by the end of the decade. Indonesia and the Netherlands are considering building a system appropriate for the Tropics in the 1990's. Two facts are highly significant to the U.S. debate: 1) in addition to the indigenous capabilities, these foreign systems rely directly on experience and technology their designers have gained from U.S. R&D efforts; and 2) they are designed to be operational, rather than R&D, systems. Some of these systems will be technically directly competitive with the current Landsat system; some will far exceed Landsat's capacity to return useful data to data users.

The following summarizes briefly the characteristics of the foreign systems. In order of planned deployment, they are:

- **West Germany—Modular Optoelectronic Multispectral Scanner (MOMS)—(1984/85).** This instrument was flown on the Shuttle Pallet Satellite (SPAS) developed by Messerschmitt-Boelkow-Blohm GmbH (MBB) aboard shuttle flight 7. MBB, COMSAT, and the Stenbeck Reassurance Co., Inc., wish to market selected 20-meter resolution multispectral (2-color) land remote-sensing data collected on shuttle flights beginning in 1984. NASA's agreement will be needed. The West Germans are developing a stereoscopic sensor and have already tested a limited synthetic aperture radar aboard Spacelab on shuttle flight 9.
- **France—Systeme Probatoire d'Observation de la Terre (SPOT)—1985.** Since 1978, the French have been planning the world's first commercial remote-sensing satellite service. They expect to fly a series of four satellites. Although the first satellite will not be launched until January 1985, they are currently preparing the sales market through a French Government-owned company, SPOT-Image. A Washington-based American subsidiary called SPOT-Image Corp. is now

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[10] *UNISPACE '82: A Context for International Cooperation and Competition,* op. cit., app. H.

developing the U.S. market for SPOT data. The U.S. corporation has flown a successful series of tests from high-altitude aircraft over the United States using sensors designed to simulate the data that will eventually flow from the SPOT system. Customers from U.S. private firms, State governments, and the Federal Government have purchased data sets from these flights.

The SPOT satellite will carry pointable multispectral linear-array sensors capable of resolving images at least as small as 20 meters in three wavelength bands. In addition, the satellite will be capable of 10-meter resolution operating in a panchromatic mode. These are higher resolutions than are possible on Landsat 4 or D′. Because the sensors are pointable, they are capable of producing quasi-stereo images. Although the system is a commercial effort, the French Government is spending a minimum of $400 million to develop the system and will subsidize its operation for a period.

- **India-IRS (1985).** This low-resolution "semi-operational" land remote-sensing satellite will be built in India but launched by a Soviet launcher. It will carry solid-state sensors.
- **Japan Marine Observation Satellite-1 (MOS-1)—1986.** The MOS-1 will carry sensors capable of resolving objects 50 meters across in three visible and one infrared (IR) wavelength bands. It will also carry a microwave scanning radiometer and a variable-resolution radiometer (900 to 2,700 meters) with one visible and three thermal IR bands. Although this satellite is being developed primarily for ocean sensing of wave heights, ocean color, and temperature, these data will also be useful for land remote sensing. The Japanese are also planning a land remote-sensing satellite (JERS-1), which is planned for launch by 1990. It will carry a synthetic aperture radar. They have not yet announced plans for distributing or selling data from MOS-1 or JERS-1.
- **European Space Agency (ESA) Remote Sensing Satellite, ERS-1—1987/ 88.** This satellite is planned primarily for passive sensing of the coastal oceans and weather over the oceans. In addition, it will carry a synthetic aperture radar for active sensing of land masses through any cloud cover. It is the first of a planned series of three satellites to be launched by ESA.
- **Canada Radarsat—1990.** Under development by Canada for routine observations of polar sea ice, the satellite will provide C-band radar images of Earth's surface. It will have a steerable beam and a spatial resolution of about 30 meters and be able to gather information on the surface of Earth through cloud cover. Data from this satellite will be available for direct sale or by arrangement though offset programs. In order to reduce its costs, Canada is seeking partners in this venture, and is discussing the possibility of working with the United States.
- **Brazil**—Brazil is working on a moderate-resolution land-sensing satellite to be launched in the late 1980's.

It is evident from this too brief summary that other countries, building on the experience gained from U.S. applications technology as well as on their own capabilities, see the development of the full range of remote-sensing satellites as an integral part of their entry into space. Besides constructing systems competitive with the U.S. Landsat system, they are also developing systems that will sense the physical parameters of the oceans and the coastal waters. The United States, though it has a program within NASA to develop new sensors to fly on the relatively short shuttle missions, has announced no plans to develop civilian operational systems that would provide data over the long term with repeat coverage. Thus, the United States, to obtain certain important data, may have to rely on foreign systems. In the absence of a Government system, or strong Government support for a private system, the private sector would be left to compete with foreign government-funded enterprises.

For research purposes, and for certain civilian Government requirements, these data will suffice. However, as is discussed in chapter 6, foreign suppliers will hardly be appropriate to supply U.S. intelligence and defense data. In the event appropriate U.S. civilian data are unavailable, the Department of Defense might seek to develop its own system.

Chapter 4

Public Interest in Remote Sensing

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Chapter 4

Public Interest in Remote Sensing

U.S. land and meteorological remote-sensing systems have from the beginning been intended to serve the public interest, whether primarily for research, as in the case of the Landsat system, or for operational weather forecasting and severe weather warning, as in the case of the meteorological satellite (metsat) systems. As the debate over the best treatment of these two systems continues, it is essential to be clear about their respective roles in serving the public interest. This chapter illustrates the use of both kinds of remotely sensed data in the public and private sectors, and suggests certain conditions and requirements that might be imposed on a private sector offeror for the Landsat system.

PUBLIC-GOOD ASPECTS OF REMOTE SENSING FROM SPACE

As understood in economic theory,[1] a public good is a good or service for which it is impossible or undesirable for reasons of efficiency to charge customers a price or a user fee for services rendered. Public goods are therefore frequently provided by Government and paid for out of tax or other general revenues. Examples of public goods are streets and highways, national defense, parks and recreational areas, police services, general weather forecasts, and various informational services.

Although it is theoretically possible to charge for some public services such as weather information (in this case, say, by using coded TV signals), the cost of doing so, compared with the cost per additional viewer (the marginal cost), would be disproportionately large.* For this reason, among others, weather forecasts are provided without charge.

In addition, for weather broadcasts, it would not be prudent to charge for the most valuable aspect of the service—warnings of severe weather—since society as a whole benefits from well-informed individual citizens. The objective of having as many members of the public "consume" weather forecasts is furthered by having as low a "price" as possible—nothing. This is a second reason why weather data are provided without charge.

For most public goods, reliance on the private market to produce them would result in either no production or production at an inadequate level compared with what society as a whole might be willing to pay through taxation. Unless they are subsidized by the public, private producers are not capable of providing public goods at socially optimal levels, i.e., where price equals marginal cost, because sales revenues at prices that would assure these levels are inadequate to finance production.

For the producer, a financial problem in pricing goods at marginal cost arises whenever the marginal cost is below average cost. It becomes particularly severe when marginal cost approaches zero. However, if prices are above marginal costs—the resource cost of servicing the consumer—some potential consumers are then priced out of the market. Production will then not reach socially optimal levels. This latter problem is also most severe for the consumer when marginal costs approach zero, if price is set equal to full (average) system cost. The conflict between financial efficiency and social efficiency is inherent in the nature of public goods.

In part because of these considerations, the metsat systems, both foreign and domestic, have always been operated by the Government, and weather data have been distributed gratis to the public. Current policy dictates that general-purpose weather data will continue to be distributed free, even if they are eventually supplied by private firms under contract to the Government. The Government has clearly chosen social efficiency as the goal in the case of meteorological satellites.

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[1] For example, Richard A. and Peggy B. Musgrave, *Public Finance in Theory and Practice*, 3d ed., ch. 3 (New York: McGraw-Hill, 1980).)

*When the marginal cost—that is the cost of servicing an extra customer—is zero and a person's consumption of the service does not reduce the benefit derived by others, we have the case of a "pure public good," since there is no rational social reason to exclude anyone from consuming it, even if it were possible to do so.

A few of the specialized services now provided by the National Oceanic and Atmospheric Administration (NOAA), on the other hand, might be provided profitably at socially desirable levels by profitmaking private firms, using the initial satellite weather data as the input. Services such as providing fruit frost warnings from the geostationary satellites or ocean surface temperature charts could fall into this category if there were sufficient interest in the private sector. A small value-added industry already uses data provided by the meteorological satellites to provide tailored weather services for a variety of customers. Thus, meteorological remote-sensing services, as presently provided, are a mixed public/private good.

It would be a mistake to conclude that just because a good has the features of a public good that it should necessarily be financed through the public budget and distributed free. The decision depends in part on whether or not Congress decides that it wants to bestow the benefit directly on those who benefit and pay for it out of tax revenues. The simplest case is when the tax payers benefit in proportion to the taxes they pay. Then making the service in question available from public revenues is relatively straightforward.

The public is unwilling to finance some public goods, however, because they are seen primarily to benefit narrow interest groups. As a consequence, some public goods are produced by the private market at nonoptimal levels. The public interest was just not great enough to result in public subsidy.

Services using data from the Landsat system could also be considered a mixed public/private good. For Landsat, however, the private-good aspects are much stronger than they are for the meteorological satellites because Landsat data have potentially high economic value. The cost of producing extra images is extremely small once the system is in place, making it undesirable from the point of view of social efficiency to recover the cost of the system by charging a price equal to the average system cost, since marginal users of images would then be charged much more than the marginal costs of servicing them. This is the public-good part of the Landsat services. As in the case of weather data, the value-added industry is a normal profitmaking industry (once it has its digital input) and thus produces private goods.

The big difference between the weather and land remote-sensing systems is that land remote-sensing customers such as oil companies, mining companies, and even municipalities in some other State are not the entities that the public prefers to subsidize. Nevertheless, the Federal Government itself is the largest user of the Landsat system—for land management, agriculture, forestry, mapping, and for foreign intelligence (ch. 5).[2] Therefore, there are significant public purposes that would in any case result in budgetary expenditures. When such a situation exists—i.e., an industry with the characteristics of a public good that also has the Government as a principal customer—Government production is a natural outcome.

At present, Landsat is also available as a partially subsidized Government-produced service to a variety of domestic and foreign users. Under this arrangement, which arose initially because of the research and development (R&D) nature of the system, Landsat has been used by State and local governments for rangeland, forest and water-resources management, by resource companies as an aid in resource definition, and by a variety of other private, profitmaking and nonprofit organizations. Some analysts predict that the market for data and for data products from space will one day expand and grow into a major industry.[3]

The issue before Congress is whether to consider land remote sensing primarily a public good or a private good. If Congress considers it primarily a private good, direct commercialization makes sense. The remote-sensing industry would join the thousands of other unsubsidized American industries producing private goods.

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[2] See also *Civilian Space Policy and Applications* (Washington, D.C.: U.S. Congress, Office of Technology Assessment, OTA-STI-177, June 1982), apps. B and C.

[3] Donn C. Walklet, "Remote Sensing Commercialization: Views of the Investment Community," ERIM Conference, May 9-13, 1983.

However, if Congress considers the Landsat system to be primarily a public good and decides that Government should not itself produce the good a further issue arises—how much, if any, subsidy Congress will continue to give the industry to ameliorate the efficiency problem. A related issue is how much regulation of the industry will be necessry to enable it to use other mechanisms for such amelioration.

A widely used mechanism in public utility regulation, the two-part tariff, illustrates how some of the efficiency advantages of subsidized Government provision of Landsat services can be preserved in the event that the public is unwilling to subsidize them. In this mechanism, both a system access fee and a fee that depends on usage are charged. The usage fee can be set closer to marginal cost because the upfront access charge finances part of the system cost. Departures from optimal production can be reduced in this way even if there is no subsidized provision of the service by the Government. Given the relatively large Government usage of remote sensed data, the access charges under such a scheme could possibly be assumed by the Government, not as a subsidy per se but as payment for its usage.

If the public-good aspects of land remote sensing are considered large or important to the general public, a further question arises as to whether the industry should be continued under Government ownership or under private ownership, or in some combination of Government and private ownership. Whether the industry under full private ownership and operation, even with subsidy or regulation to ameliorate the efficiency problem, would serve the public interest is an important aspect of commercialization that remains to be determined by Congress.

USERS OF REMOTE SENSING

This section enumerates the organizations, agencies and categories of private firms that are the primary users of remote-sensing data from both land and meteorological satellites. These users constitute the primary customers for a remote-sensing industry. Although the two communities of land and meteorological data users overlap one another to a certain extent, and both include domestic, foreign, and international users, in most respects they are separable.

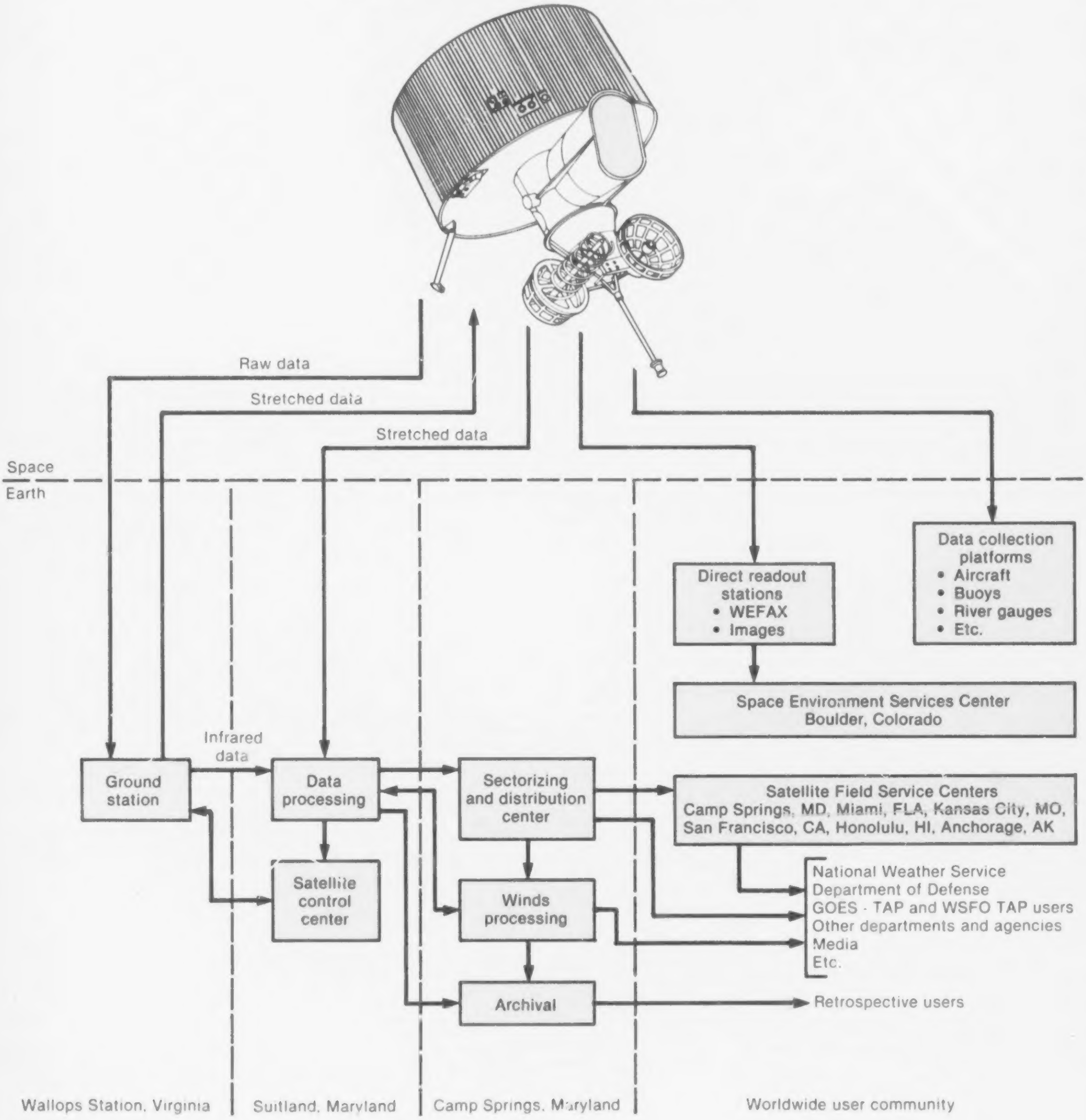
Meteorological Data

The largest domestic user of metsat data is the general public, with NOAA as supplier. The National Weather Service has a vital interest in the metsat data and its sister agency, the National Environmental Satellite and Data Information Service, operates the U.S. Weather Satellite system currently consisting of two geostationary and two polar-orbiting satellites—respectively GOES East and GOES West and NOAA-7 and -8 (figs. 2, 3). Both qualitative and quantitative data are collected, processed, and distributed via communications networks. Other users are included in table 2.

Prominent among the domestic private sector users of metsat data products are the airlines, private meteorological forecasting companies, the fishing industry, sea-ice consultants, agricultural industries, and a large number of research specialists such as climatologists, hydrologists, and oceanographers. Many of these people are engaged in pioneering studies involving water-resources management; others use the satellites' communication capabilities from terrestrial data-collection platforms to monitor various parameters such as water, soil, or plant temperatures or snow depth for practical, operational management decisions.

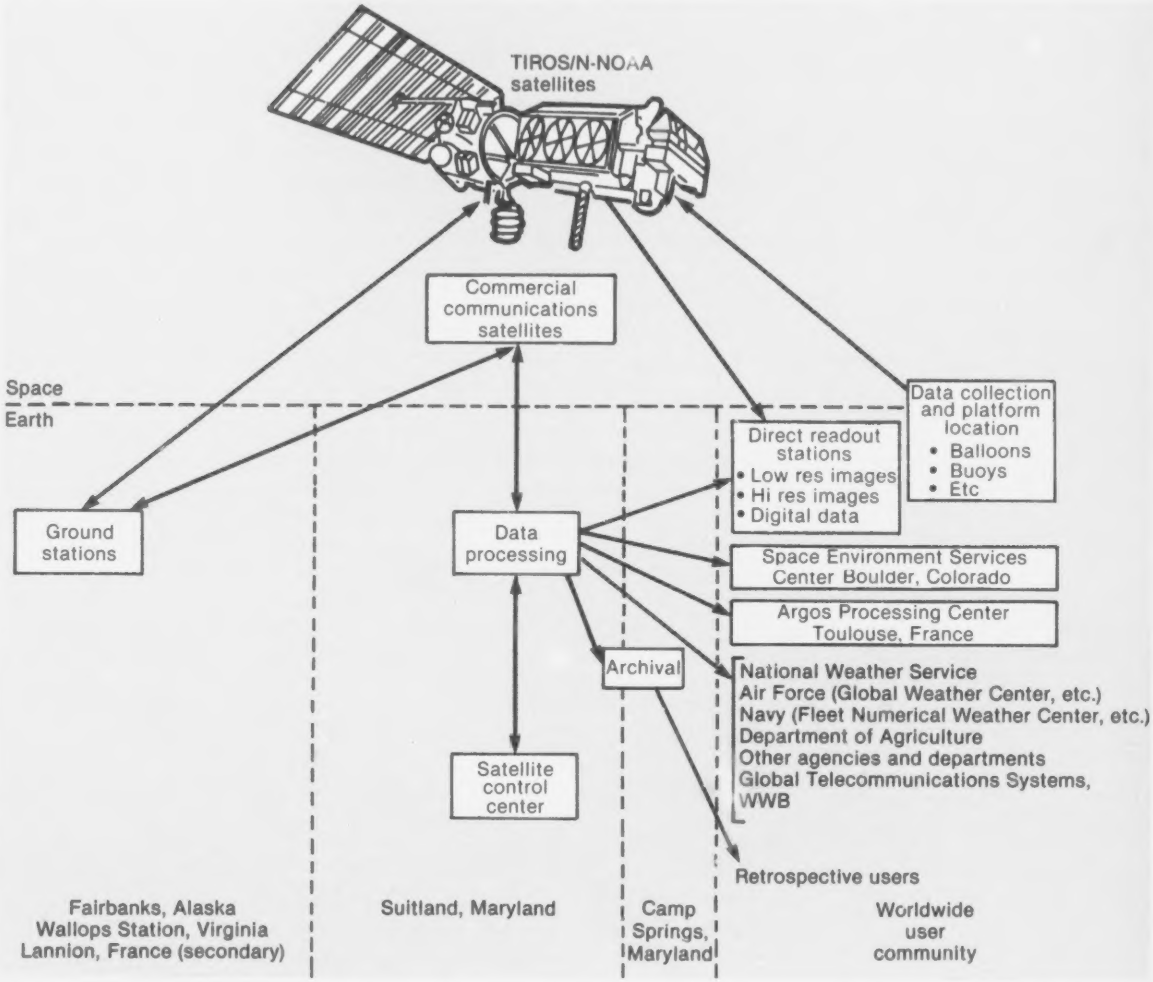
Foreign users of metsat data are many. The most popular aspect of the early metsat program was the free availability of the U.S. meteorological satellite data to all countries through the Automatic Picture Transmission program. This program engenders much good will for the United States throughout the world. Inexpensive antennas and receiving equipment enabled even the poorest of the third-world nations to have weather satellite images for better weather forecasting. The Canadians have taken particular advantage of these data to provide better forecasting and bet-

Figure 2.—Geostationary Satellite System


Raw data
Stretched data
Stretched data
Space
Earth
Direct readout stations
• WEFAX
• Images
Data collection platforms
• Aircraft
• Buoys
• River gauges
• Etc.
Space Environment Services Center Boulder, Colorado
Infrared data
Ground station
Data processing
Sectorizing and distribution center
Satellite Field Service Centers
Camp Springs, MD, Miami, FLA, Kansas City, MO, San Francisco, CA, Honolulu, HI, Anchorage, AK
Satellite control center
Winds processing
National Weather Service
Department of Defense
GOES - TAP and WSFO TAP users
Other departments and agencies
Media
Etc.
Archival
Retrospective users
Wallops Station, Virginia
Suitland, Maryland
Camp Springs, Maryland
Worldwide user community

SOURCE: National Oceanic and Atmospheric Administration.

Figure 3.—Polar-Orbiting Satellite System


TIROS/N-NOAA satellites
Commercial communications satellites
Space
Earth
Data collection and platform location
• Balloons
• Buoys
• Etc
Direct readout stations
• Low res images
• Hi res images
• Digital data
Ground stations
Data processing
Space Environment Services Center Boulder, Colorado
Argos Processing Center Toulouse, France
Archival
National Weather Service
Air Force (Global Weather Center, etc.)
Navy (Fleet Numerical Weather Center, etc.)
Department of Agriculture
Other agencies and departments
Global Telecommunications Systems, WWB
Satellite control center
Retrospective users
Fairbanks, Alaska
Wallops Station, Virginia
Lannion, France (secondary)
Suitland, Maryland
Camp Springs, Maryland
Worldwide user community

SOURCE: National Oceanic and Atmospheric Administration.

Table 2.—Domestic Distribution of Polar Satellite Products

- National Weather Service
- Environmental Research Laboratory
- Other NOAA offices
- Department of Agriculture
- Department of the Interior
- National Aeronautics and Space Administration
- Department of Defense (Air Force and Navy)
- Coast Guard
- Academic community
- Commercial users (e.g., farmers, fisheries, oil companies, engineering and consulting companies)
- Private individuals
- State governments

SOURCE: Office of Technology Assessment.

ter data for the more remote and inaccessible portions of their vast country. About 125 countries of the world similarly collect data using their own collection stations (see table 1 in ch. 3).

Certain scientific disciplines, such as meteorology, climatology, oceanography, and geology, transcend political boundaries because the boundary conditions they deal with are physical rather than national. Study of global phenomena requires global cooperation. The need for international cooperation in these disciplines has led to international programs (e.g., the International

Hydrological Decade) and organizations (e.g., the World Meteorological Organization).

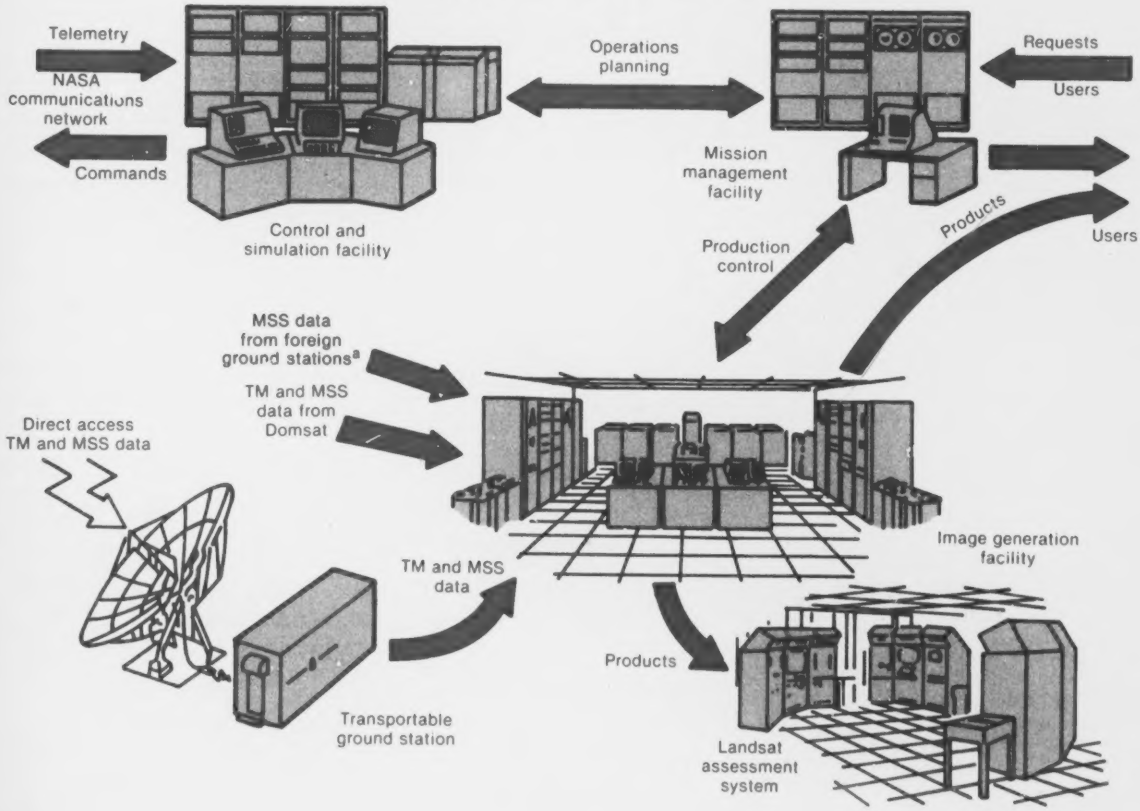
Land Resource Data

The Landsat system (fig. 4) possesses several properties that permit the development of a global data base for resource inventory and monitoring over time:

- perspective over a range of selected spatial scales;
- selected combinations of spectral bands for categorizing and identifying suface features;
- repetitive coverage over comparable viewing conditions;
- direct measurement based on one set of reflectance conditions for a wide surface area;
- signals suitable for digital storage and subsequent computer manipulation; and
- accessibility over remote and difficult terrain and across political divisions.

As with the meteorological data, the largest single user of Landsat data is the Federal Government (see table 3). Within the Government, the Department of Agriculture (USDA) and the intelligence community are the two greatest users. Both of these agencies and the other Federal agencies combine these data routinely with other information to assist their missions.

Figure 4.—Major Elements of the Landsat System


Telemetry
NASA communications network
Commands
Control and simulation facility
Operations planning
Requests
Users
Mission management facility
Users
Products
Production control
MSS data from foreign ground stations[a]
TM and MSS data from Domsat
Direct access TM and MSS data
Image generation facility
TM and MSS data
Products
Transportable ground station
Landsat assessment system

[a] Prior to TDRSS Phase-in.

SOURCE: National Oceanic and Atmospheric Administration

Table 3.—Domestic Distrubition of Landsat Products

- Department of Agriculture
- Department of Defense
- Department of the Interior
- National Aeronautics and Space Administration
- Intelligence community
- Coast Guard
- State planning and resource management agencies
- Regional planning agencies
- Academic community
- Commercial users (e.g., foresters, mineral exploration geologists, engineering and consulting companies)
- Private individuals

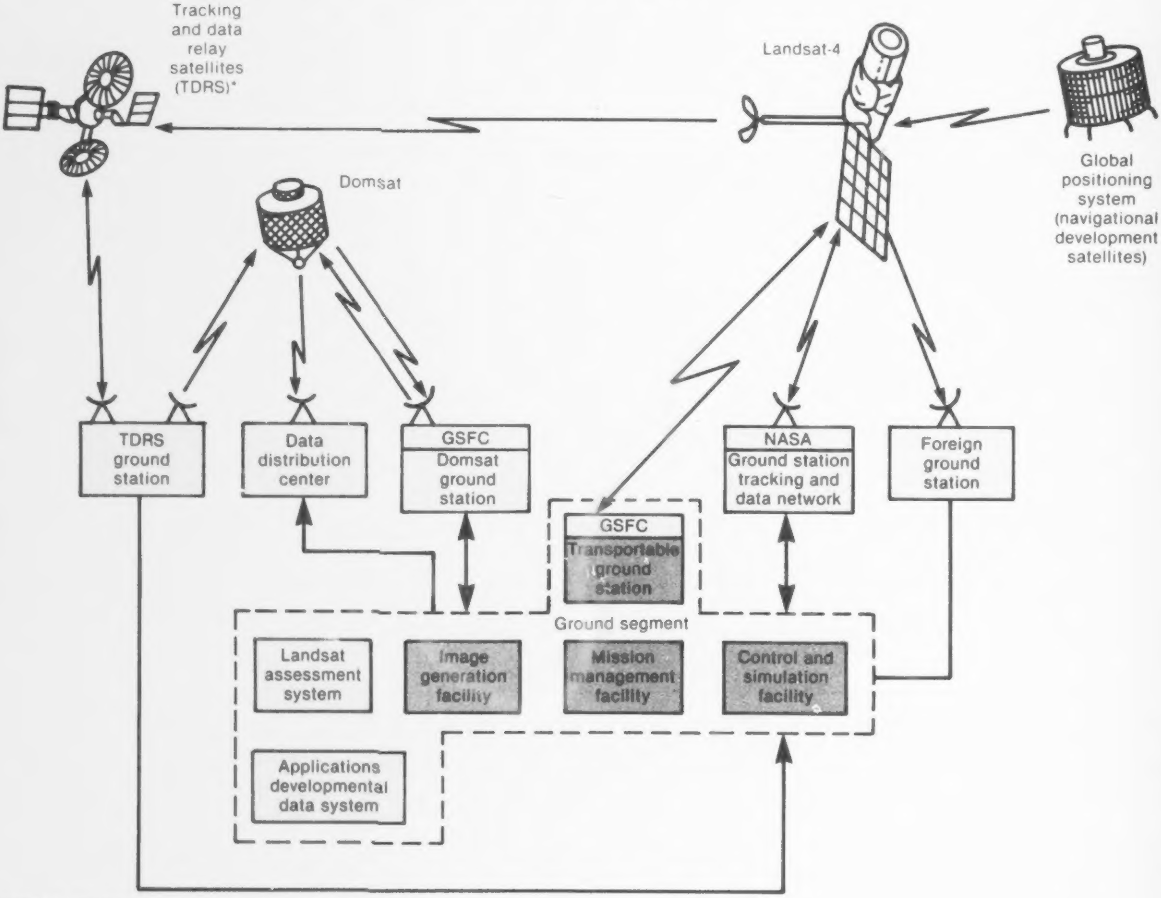
SOURCE: Office of Technology Assessment.

The major commercial customers of Landsat data include the agriculture, forestry, mineral industries, and land-use planners, directly or indirectly through the value-added industry (discussed below). The academic community (discussed below) primarily supports the research efforts of Federal and State agencies and the private sector.

The Value-Added Industry

Transfer of the land remote-sensing program to the private sector is likely to introduce both desirable and undesirable changes in the remote-

Landsat Ground Segment


Tracking and data relay satellites (TDRS)*
Landsat-4
Global positioning system (navigational development satellites)
Domsat
TDRS ground station
Data distribution center
GSFC
Domsat ground station
NASA
Ground station tracking and data network
Foreign ground station
GSFC
Transportable ground station
Ground segment
Landsat assessment system
Image generation facility
Mission management facility
Control and simulation facility
Applications developmental data system

SOURCE: National Oceanic and Atmospheric Administration.

Landsat Data Needs of Foreign and Domestic Users

- *Agriculture* (Federal, State, and private): specific sampling areas chosen according to the crop; time-dependent data related to crop calendars and the weather patterns
- *Forestry* (Federal, State, and private): specific sampling areas; twice per year at preselected dates
- *Geology and nonrenewable resources* (Federal, State, and private): wide variety of areas; seasonal data in addition to one-time sampling
- *Civil engineering and land use* (State and private): populated areas; repeat data required over scale of months or years to determine trends of land use
- *Cartography* (Federal, State, and private): all areas; repeat data as needed to update maps
- *Coastal zone management* (Federal and State): monitoring of all coastlands at selected dates depending on local seasons
- *Pollution monitoring* (Federal and State): broad, selected areas; highly time-dependent needs both for routine monitoring and in response to emergencies

SOURCE: Office of Technology Assessment.

sensing value-added industry. This small but expanding industry exists both as small units of large resource companies and as independent smaller companies. The business base of the independent companies has developed since the late 1960's in parallel with the Nation's space-borne remote-sensing program. Value-added operations of various types exist not only in the United States but also in free-market European countries and Japan. The availability of remotely sensed data on an unrestricted basis at an acceptable cost is essential to the continued strong growth of this industry.

Data services or products furnished by value-added firms range from improving the image by simple processing of the raw data, to the provision of information services specific to various natural resources industries. Petromining, agriculture, hydrology, land-use planning, and oceanographic companies all benefit from services provided by value-added companies. In many cases the firms supplying services and products based on remotely sensed data provide information that can significantly alter the way many industries make decisions.

Presently, over 50 commercial organizations in the United States provide analyses of remotely sensed data. They or their customers use the imagery acquired from space to evaluate specific areas of Earth's surface for hydrocarbon resource potential, estimating future crop production and water resources, and surveying land use. Several of these firms also sell hardware designed to process data remotely sensed from space.

A strong value-added industry is essential to creating a self-supporting land remote-sensing business. For example:

> Without the competitive nature of a strong value-added industry it is unlikely that the products, the services, and the multilevel derived geological information will be made available to the private sector energy and mineral explorationist with whom the U.S. Charter for finding our future nonrenewable resources lies. If so, no commercial market is likely to evolve.[4]

It is also important to recognize that profitmaking value-added firms exist in an infrastructure including other entities that provide ancillary data, onsite inspection, and a variety of related services. Important among these are the Government laboratories and management units that provide an essential research base from which the value-added companies derive some of their information-processing techniques.

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[4] Frederick B. Henderson, "The Significance of a Strong Value-Added Industry to the Successful Commercialization of Landsat," presented at the 21st Goddard Memorial Symposium, Mar. 24-25, 1983.

USING LANDSAT DATA FOR FORESTRY AND AGRICULTURE

Landsat data have been used in a variety of fields where low- to moderate-resolution spectral data can be integrated with other information to provide analyses important to the exploitation and management of resources. This section presents examples from two areas where these data appear to be especially helpful: forestry and agriculture. It specifically excludes discussion of petroleum and other mineral exploration because these have been discussed in considerable detail in other publications.[5] However, the petroleum and mineral exploration industry is now the largest private purchaser of Landsat data. Its relative importance for the near-term prospects of commercializing land remote sensing is high.

Forestry

In forestry, as in many other disciplines involving land management, there is a distinct need for timely, reliable information about the resource base. The "synoptic view" provided by images obtained from spacecraft altitudes is proving valuable when information over extensive geographic areas is required, as is the case in managing our Nation's forest resources. For instance, the Forest and Rangeland Renewable Resources Planning Act of 1974, in which Congress mandated the U.S. Forest Service (through the Secretary of Agriculture) to provide information on the condition and productivity of approximately 1.6 billion acres of public and private land every 10 years, emphasized the need for efficient, cost-effective systems to collect detailed data periodically over very large areas.

Numerous other examples could be cited of requirements for accurate, detailed information for a wide variety of resource-management and/or policy decisions. These range from the needs of an individual forester who works for a single forest company and makes market-related decisions about a specific block of land to those of State or Federal legislators who must make policy decisions which could affect forests and other natural resources of an entire State or of the Nation for decades to come.

In at least three respects, the characteristics of the information required for effective and efficient management of forest resources are unique. First, the forests are so extensive, both nationally and globally, that the quantity of data needed is gigantic. Second, the forests are highly complex and diverse, which results in the need for detailed information on their various components. There are different species and species mixtures, different age classes, and varying stand densities. Third, the forest grows slowly but can be harvested or adversely affected relatively quickly, which makes inventorying and characterizing the forests expensive. Yet, because of both human and natural influences (e.g., insects, disease, severe weather) on the extent and condition of forest resources, inventories of some type are mandatory. The interval between inventories might well vary, depending on the type and severity of the particular changes expected. In sum, the demands for the type and frequency of information concerning forest resources are quite different from those involving crops, water, or mineral resources.

Because of these special information requirements and economic limitations peculiar to forestry, the Landsat system is uniquely capable of obtaining the type and quantity of data needed. Only the Landsat system provides reasonably detailed data (i.e., each pixel or minimum element of Landsat data represents 1.1 acres on the ground), over the forested regions of the **entire Earth**, at very modest cost (on a per-acre basis),* and at a frequency that allows most changes to be monitored effectively. However, if the cost of the data used for forest inventories, on either a local or worldwide basis, is too high, such data will not and cannot be used to obtain the necessary information. Management decisions will, by necessity, continue to be made, but may be based on inadequate, outdated, resource information.

The advantages and limitations of Landsat data to foresters, and examples of the use of Landsat data are discussed in some detail in appendix F. The following paragraphs summarize its conclusions.

Three major groups involved in forest resource management have found Landsat data to be particularly effective:

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[5] Alexander F. H. Goetz and Lawrence C. Rowan, "Geological Remote Sensing," *Science*, vol. 211, 1981, pp. 781-790; "Satellite Remote Sensing Data—An Unrealized Potential for the Earth Science Community," The Geosat Committee, Inc., 1977; "Remote Sensing and Exploration Geology," Proceedings of the Geosat Panel Discussion, COSPAR Conference, May 21, 1982, Ottawa, Canada, Geosat Technical Report No. 3.

*Current cost per computer-compatible tape covering approximately 13,225 square miles is $650.00, which is less than $0.05 per square mile, or less than 1/100 cent per acre. However, this cost figure does not include sizable data acquisition or data analysis costs. Also, because aerial photos contain much more detailed information, and can be ordered to cover smaller, more discrete areas, many users are willing to pay much higher costs for aerial photography than for Landsat data.

- **Forest industries.** The St. Regis Paper Co. has found Landsat data cost-effective in increasing efficiency of forest mapping, and improving field operations. Although other forest companies have shown interest in using Landsat data, they are reluctant to invest the time, money, and personnel necessary to use a new technology in their operations when the continued availability of Landsat data is in considerable doubt. They are also fearful of continuing price increases that would decrease the cost-effectiveness of the data. In addition, in forestry, the use of land remote-sensing data has not reached the operational level that has been obtained in the geosciences. Continued research by the companies will be needed to determine just how to use the data most effectively under day-to-day operational conditions.
- **Federal and State agencies.** The Federal Bureau of Land Management (see app. F) uses Landsat data for managing forests and rangelands under its care. In addition, States such as Minnesota, Mississippi, and Pennsylvania, as well as regional groups of States, have explored the use of Landsat imagery to aid in monitoring their forest lands (see apps. D and E).
- **Foreign countries.** One of the primary resource concerns in other countries, particularly developing countries in tropical regions, is the rapid loss of forests because of clearcutting for agricultural purposes and for fuel. Landsat data are particularly cost effective (at current subsidized prices) for monitoring the rate of deforestation (see apps. A and G). They have been used for this purpose in Brazil, the Philippines, Thailand, the Dominican Republic, Nigeria, and Costa Rica. A critical factor in the future use of Landsat data, however, will be their cost as well as their timely availability. Many of these data were supplied by the Agency for International Development (AID) as part of the U.S. effort to make Landsat data available to developing countries. If AID dramatically reduces the support it gives to land remote-sensing research programs in other countries (see ch. 3), their ability to monitor the rate of deforestation will decrease accordingly.

Remote Sensing for Agriculture

Drawing on the information and analysis of appendix D, this section summarizes the use of remote sensing for agriculture. Land and meteorological remote sensing provide only some of the data important to planning agricultural production. Yet, as agricultural analysts have gained experience in applying these data, the data have increased in importance. The repeatability, synoptic view, and spectral and spatial characteristics of satellite-derived systems could make agricultural prediction and planning over wide geographical areas much more reliable than it now is.

Soon after the launch of the first Landsat satellite, USDA entered a joint research program with the National Aeronutics and Space Administration (NASA) and NOAA, called the Large Area Crop Inventory Experiment (LACIE). This program developed software to estimate grain production in the Soviet Union and Canada. LACIE experienced both successes and failures, but showed enough potential for USDA to develop a joint research program with NASA, Agriculture and Resource Inventory Surveys through Aerospace Remote Sensing (AgRISTARS). The AgRISTARS program seeks to develop satellite remote sensing for practical agricultural purposes.

Most of the agencies at USDA are able to use satellite data to support their missions. Much of this current know-how resulted from either LACIE or AgRISTARS. In the private sector, several companies have learned how to combine meteorological with Landsat data to predict future crop yields. These data are important to Government agricultural planners as well as to farmers, farm cooperatives, and merchants and traders who buy and sell farm commodities.

Although remote-sensing data satisfy a small part of the total information needs of agriculture, timely delivery of accurate, comprehensive, objective, remote-sensing data could improve most of the information areas for agriculture (table 4) if the data were inexpensive enough.

Table 4.—Information Needs of Agriculture

Information type	Remote-sensing data could improve quality
Resources:	
Physical	•
Human	
Economic	
Farmer/producer behavior	
Agronomy	•
Current crop and livestock	•
Market news	•
Economic predictions	•

SOURCE: Office of Technology Assessment.

Criteria of a Good Agricultural Information System[6]

Satellite technology has tremendous potential to supply data with the necessary characteristics. However, this potential has yet to be realized with Landsat technology. Data from the meteorological satellites meet most of the necessary criteria, especially cost-effectiveness and timeliness, but the low spatial resolution and limited spectral characteristics of the metsat data necessarily limit their overall effectiveness for agriculture. These criteria are:

- **Accuracy.** To be used for predictive purposes, data must contain acceptably small errors. Satellite data have the potential to be both precise and accurate, but considerable research on the data is needed to determine how to reduce sampling errors. In the meantime, the data are being used to predict future crop yield.
- **Timeliness.** Agricultural decisions require data that are no more than a few days to 2 weeks old, depending on the particular decision to be supported by these data.
- **Cost-effectiveness.** To achieve maximum usefulness to the agricultural community, satellite data must be cost-effective compared to older, less efficient, but more familiar ways of gathering data (i.e., ground and aerial survey).
- **Expandability.** An effective information system must be able to adapt to new modes and new technologies without increasing costs excessively. Satellite technology has the potential of making objective, accurate crop yield measurements with current data for large farm plots. The thematic mapper (TM) and other proposed sensors having high spectral resolution are expected to increase the accuracy of these measurements and allow sampling of smaller fields as well.
- **Repeatability.** Surveys made at different times should reflect changes in the target population rather than alterations in the methods for collecting data. Remote sensing from space makes possible highly repeatable data characteristics. Because the Landsat system has been a research effort until recently, data format, spectral and spatial characteristics, and orbital characteristics have changed over time. Such changes make it difficult to compare images taken at different times.

Implications of Improved Information for Agriculture

Global, timely, reliable information on major food and fiber crops is a significant element of national economic and political intelligence. Such information may affect a broad spectrum of public and private sector activities. Better information, distributed in a timely way, could lead to more equitable sharing of the profits and losses of farming activities. Of more importance, it might lead to avoidance of spot shortages or of overproduction in particular geographical areas. It could also reduce the total energy consumption devoted to agricultural production.

Because the agricultural community needs repetitive data over periods of days, weeks and months, it would be the major customer for land remote-sensing data if good data can be delivered promptly and cheaply.

Concerns of the Agricultural Community

- **Costs.** For fiscal year 1984, USDA has allocated $7.4 million to purchase the Landsat data it needs. However, potential private customers are likely to make little use of Landsat data until the cost per scene is reduced considerably, the data can be delivered promptly and the costs of analysis can be reduced.

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[6] Howard W. Hjort, "World Agricultural Information System: A Critical Evaluation," contract report for OTA, September 1975.

- **Continuity.** Agricultural statistics assume greater meaning when collected and analyzed over time. Current data must be compared with those of earlier years. For the agricultural community to make more use of land remote-sensing data, data format should be standardized and the data should be available promptly and continuously, without gaps in delivery.
- **Copyright.** Existing legislation charges several different Government agencies with managing our national resources. Landsat data have begun to play a significant role in meeting this responsibility. For these agencies to use the data effectively, they must be able to pass them freely among themselves. Copyright restrictions on data, if imposed by a private operator, could impede the free exchange of information among Government offices.
- **Data control.** Although grain companies and other agricultural firms are not now large users of Landsat data, they are interested in the technology. Some agricultural analysts fear that a policy allowing discriminatory access to data might result in predatory marketing practices. Theoretically, a firm that could pay for first access to the data would have an unfair advantage and could make windfall profits simply by postponing availability of data to the outside world. This is especially crucial in agriculture, where the value of the data is highly time-dependent.
- **Technological improvements.** Parts of the agricultural community are concerned that transferring the Landsat system might result in a freeze of technology at the current level of sophistication. In their view, not only improved sensors are important, but lower cost, improved image-processing.

STATE AND REGIONAL USE OF LANDSAT DATA

Because computers are now used in most States and regional organizations, Landsat data find a ready niche in their resource information systems. With considerable assistance from NASA, many States have purchased the hardware, software, and training to process Landsat data. At least 18 States have now merged Landsat data with other data in broad-based geographic information systems (table 5). Some of these systems can use Landsat data directly (app. B).

A prime example is the State of Mississippi, where Landsat data are integrated directly in a single information system—the Mississippi Automated Resource Information System (MARIS). When operating fully, MARIS will provide a catalog of natural resources and cultural data about the State, interpretive maps, and the analytical staff to analyze and interpret trends (app. B). Landsat data are being used in Mississippi to identify and study the available nuclear waste-disposal sites, ground water depletion, and the amount and type of ground cover. Landsat data have been found to be highly cost effective in meeting Mississippi's resource information needs.

Because of their synoptic coverage, Landsat data are particularly useful for regional management. In 1975, the Pacific Northwest Regional Commission, with support from NASA and the U.S. Geological Survey, started a project to investigate the applications of Landsat data to a variety of resource problems in the Pacific Northwest. The project's goal was to integrate these data with other data on the region's vegetation, soils, and terrain. The Pacific Northwest is particularly interesting ecologically because it is the site of two major, but contrasting, ecoregions—the Humid Temperate Domain of the coastal areas of Washington and Oregon, and the Dry Domain east of the Cascade Mountains.

Participants in the study concluded that the Landsat system was a cost-effective source of management data. However, a "critical mass" of individual agencies is necessary to prove the value of Landsat data on a State or regional basis. Although the cost of the necessary processing hardware and software constitutes a barrier to using Landsat data, "the most critical element is continuity of data. Without assurance of continui-

Table 5.—Summary of Operational Landsat Applications in the States

A. **Water resource management**
- Surface water inventory
- Flood control mapping and damage assessment
- Snow cover mapping
- Water resources planning and management
- Irrigation demand estimation
- Determination of runoff from cropland
- Watershed or basin studies
- Water circulation
- Lake eutrophication survey
- Irrigation/saline soil
- Geothermal potential analysis
- Ground water location
- Offshore ice studies

B. **Forestry and rangeland management**
- Forest inventory
- Forest productivity assessment
- Clearcut assessment
- Forest habitat assessment
- Wildlife range assessment
- Fire fuel potential
- Fire damage assessment and recovery

C. **Fish and wildlife management**
- Wildlife habitat inventory
- Wetlands location and analysis
- Vegetation classification
- Snow pack mapping
- Salt exposure

D. **Land resources management**
- Land cover inventory
- Comprehensive planning
- Corridor analysis
- Facility siting
- Flood plain delineation
- Solid waste management
- Lake shore management

E. **Environmental management**
- Water quality assessment and planning
- Environmental analysis or impact assessment
- Coastal zone management
- Surface mine inventory and monitoring
- Wetlands mapping
- Lake water quality
- Shoreline delineation
- Oil and gas lease sales
- Resource inventory
- Dredge and fill permits
- Marsh salinization

F. **Agriculture**
- Crop inventory
- Irrigated crop inventory
- Noxious weeds assessment
- Crop yield prediction
- Grove surveys
- Assessment of flood damage
- Disease monitoring

G. **Geological mapping**
- Lineament mapping
- Geological mapping
- Mineral surveys
- Powerplant siting
- Radioactive waste storage

SOURCE: National Governors' Conference.

ty, States (and therefore regions) cannot accept the risks of utilizing Landsat data as a primary tool."[7] Here, as in Federal use of land remote-sensing data for resource management, it was often important to share the primary data among State agencies, a practice that copyrighting them could prevent.

REMOTE-SENSING RESEARCH WITHIN THE UNIVERSITIES

Universities use Landsat data for research in a variety of resource and land-planning applications encompassing the entire range of remote-sensing applications. They develop techniques for specific applications and carry out research on the spatial and spectral characteristics of new, more powerful sensors. The universities work with local and State governments as well as with the Federal Government and industry. In some States, university researchers constitute the major source of remote-sensing information and support. University researchers have expressed concerns about the state of land remote-sensing policy, and about the proposed transfer of land remote sensing to the private sector. They would also like to see future research needs provided for.

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[7] Letter from Governor Straub of Oregon, State co-chairman of the three-State project, to NASA Administrator, 1979.

Overview of Landsat Applications in the 50 States

State	Water resources	Forestry/ rangeland	Wildlife management	Land resources management	Environmental management	Agriculture	Geologic mapping
Alabama	X	X		X	X		X
Alaska	X		X	X	X		X
Arizona	X	X	X	X	X	X	X
Arkansas				X		X	X
California	X	X	X	X	X	X	X
Colorado	X		X	X	X	X	
Connecticut							
Delaware	X				X		X
Florida	X	X	X	X	X	X	
Georgia	X	X	X	X	X	X	X
Hawaii		X		X	X		
Idaho	X	X	X	X		X	
Illinois	X	X		X	X	X	
Indiana		X	X	X	X	X	X
Iowa	X			X	X	X	X
Kansas	X		X	X		X	X
Kentucky	X	X	X	X	X	X	X
Louisiana	X	X		X	X	X	
Maine	X	X		X	X	X	
Maryland				X	X	X	X
Massachusetts					X		
Michigan				X	X		
Minnesota	X	X	X	X	X	X	X
Mississippi	X	X	X	X	X	X	
Missouri	X	X	X	X	X	X	X
Montana	X	X		X		X	
Nebraska	X	X	X	X	X	X	X
Nevada	X						
New Hampshire		X		X			
New Jersey		X		X	X		
New Mexico		X	X	X	X	X	
New York	X	X	X		X	X	X
North Carolina	X	X	X	X	X	X	
North Dakota	X		X	X	X	X	
Ohio				X	X		X
Oklahoma	X	X		X	X	X	X
Oregon	X	X	X	X	X	X	
Pennsylvania		X		X	X		X
Rhode Island							
South Carolina	X	X	X	X	X		
South Dakota	X	X	X	X	X	X	X
Tennessee			X	X	X		X
Texas	X	X	X	X	X	X	X
Utah		X	X		X		X
Vermont		X			X		
Virginia	X	X		X	X	X	X
Washington	X	X	X	X	X		
West Virginia		X			X		X
Wisconsin	X	X		X	X	X	
Wyoming	X		X	X	X	X	X

SOURCE: National Governors Conference.

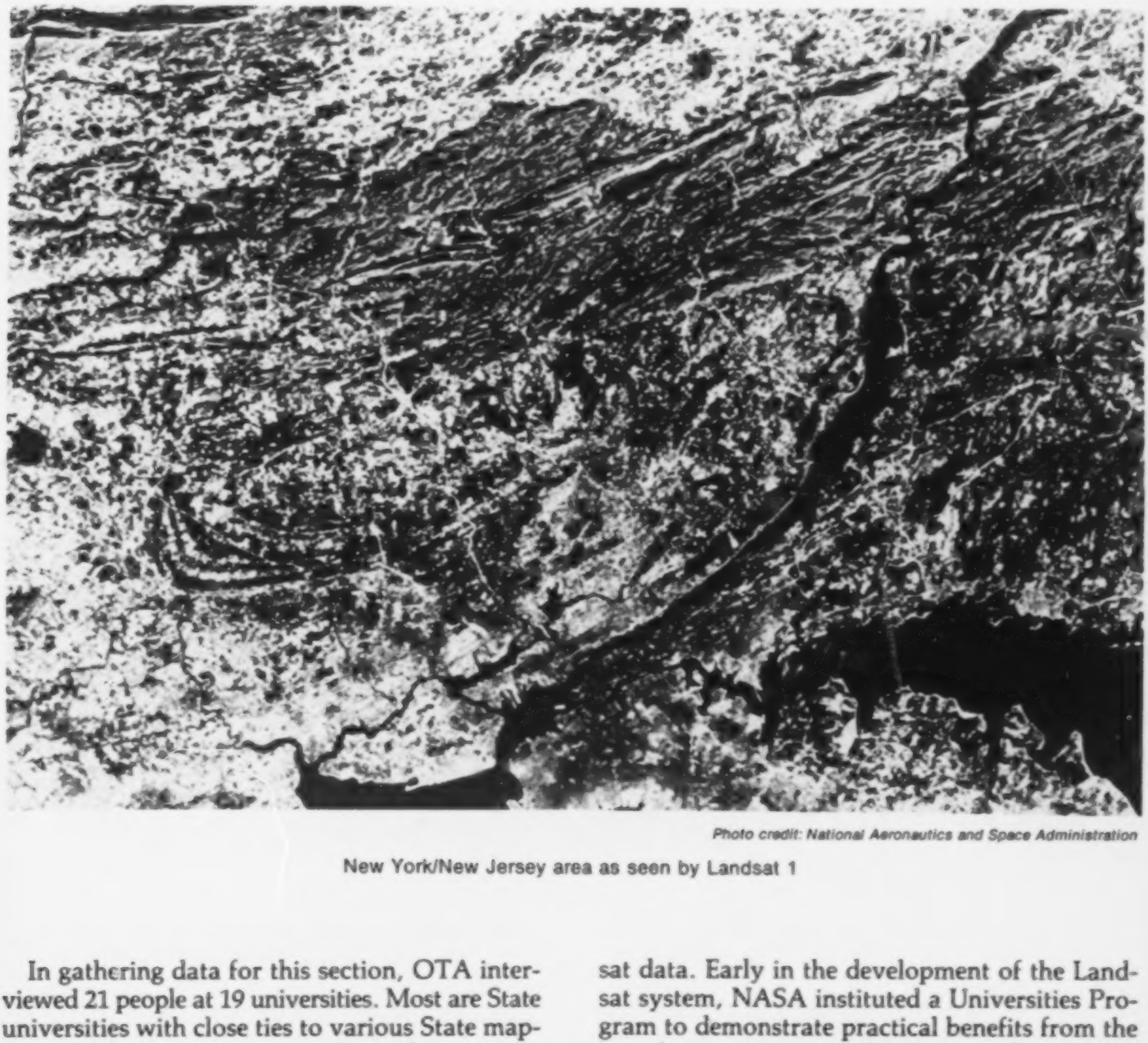

Photo credit: National Aeronautics and Space Administration

New York/New Jersey area as seen by Landsat 1

In gathering data for this section, OTA interviewed 21 people at 19 universities. Most are State universities with close ties to various State mapping and monitoring agencies that either now use Landsat data or are considering it for the future.

University Experience With NASA's Landsat Program

Because land remote sensing from space is a novel technique for obtaining information about the Earth's surface, its use requires innovative educational and training programs. With no previous community of users, exposure to the technology, training, and experience were needed to develop understanding of the potentials of Landsat data. Early in the development of the Landsat system, NASA instituted a Universities Program to demonstrate practical benefits from the use of remote-sensing technology to a broad spectrum of new users, principally in State and local governments. During the period 1972-82, NASA provided between $8 million and $10 million to universities a year as seed money for research, demonstration, and training in the uses of land remote-sensing technology.

A wide variety of State, local, and private organizations, as well as the recipient universities, matched NASA funds with direct financial support and in-kind grants. The university role assumed increased importance as NASA's satellite flight programs for remote sensing became better understood and emphasis shifted from the hardware to the resulting data and its users. A 1978 survey shows, for 20 selected universities, details about program duration, size, scope, and unique characteristics (see app. C).[8]

The interviewees generally agreed that university courses of instruction trained personnel in new applications of remote sensing. They pointed out that the close relationships established with other disciplines allowed prompt feedback to the universities, prompt assimilation of lessons, and rapid revision of instructional programs. The multidisciplinary course work and research have led to several new domestic applications of remote-sensing data. The universities have trained foreign students, conducted symposia, and assisted AID and other agencies in overseas development work. They have also assisted in introducing remote-sensing technology into the work of State and regional agencies. Their work has even resulted in the development of several small profitmaking value-added companies.

University Concerns Over Land Remote-Sensing Policy

The university remote-sensing community expresses major concerns about three general questions: 1) the future of land remote sensing in the United States, 2) the effect of current budget constraints on university research programs, and 3) the effects of future costs of Landsat data on teaching and research budgets.

University researchers worry that both the operational and research aspects of the Landsat program lack direction. Uncertainty at the Federal level has led to even greater uncertainty at the local level. Industries, as well as Federal and State agencies, are reluctant to invest in their own research programs on Landsat applications until they are assured that land remote-sensing data will be continuously, promptly, and inexpensively available. This reluctance is having a significant negative effect on remote-sensing programs in universities throughout the country.

For the multidisciplinary centers of remote-sensing research (which were put together laboriously over a decade with Federal support) to continue their work, they will require assured budgets and flow of data. Decreased activity by Federal, State, and local agencies, and by private industry has caused many university programs to be drastically curtailed—staff have been reduced, researchers have redirected their efforts elsewhere. This trend is likely to continue until the overall direction of the Landsat program is defined or until the French SPOT program becomes operational. If a strong market for land remote-sensing data were to develop, some funding through private industry would likely become available. In the meantime, universities are losing the qualified, experienced, and knowledgeable people needed for remote-sensing research.

The third major concern is the cost of Landsat data. Table 6 shows past, present, and future costs of a few of the Landsat products. For teaching purposes, a professor often needs multiple copies of a single image. Even if he or she can use the same data in subsequent semesters, it soon becomes frayed, torn, and marked up. The teaching budg-

Table 6.—Costs for Some Landsat Data Products

	Cost			
Product	Until October 1981	October 1981—October 1983	October 1983—February 1985	February 1985—???
Multispectral scanner (MSS) computer-compatible tape (CCT)	$200	$ 650	$ 650	$ 730
Thematic mapper (TM) CTT	Not available	$2,800	$3,400	$4,400
TM CCT (quarterly)	Not available	$ 750	$ 925	$1,350
Color composite image (1:250,000 scale):				
MSS	$ 50	$ 175	$ 175	$ 195
TM	Not available	$ 235	$ 275	$ 290

SOURCE: National Oceanic and Atmospheric Administration.

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[8] "Survey of University Programs in Remote Sensing Funded Under Grants From the NASA-University Space Applications Program," Battelle Columbus Labs, report No. BCL-OA-TFR-78-3, Mar. 31, 1978.

ets for supplies and equipment in many universities are extremely modest. As one university professor explained:

> Ordering just four color prints of a thematic mapper image would exhaust my entire teaching budget for all of my courses for an entire year! As of February 1985, a single frame of thematic mapper data in CCT format would cost more than is contained in my total teaching budgets for 4 years! It is quite clear that these prices will (and already have) caused me and many other teachers to modify the course content, decrease the availability of "hands on" laboratory materials for the students to use, and virtually eliminate future orders for Landsat products to use in the classroom."[9]

This and similar examples from other universities demonstrate that the long debate over the fate of land remote sensing in the United States has negatively affected the quality of education in remote-sensing techniques as well as further decreasing the volume of products being ordered.

Issues Raised by Proposed Transfer to the Private Sector

The issues of the proposed transfer are imbedded within the general concerns of the university research community towards Federal land remote-sensing policy in general:

- **Continued, open availability of data.** This is mentioned most frequently as the major issue. As understood by university researchers, it includes a predictable and affordable price structure, perhaps with special rates for nonprofit groups, and the absence of restrictions on use of the data. In other words, OTA's respondents were opposed to copyrighting the corrected data.*
- **Research and training support.** For the universities to continue their programs, they will need assurances that Federal funding for scientific research, methods-development, and training will continue. Even if the proposed transfer to private ownership is highly successful, it will take many years for the market to build to the point that the private sector and the States can support these important university programs. In the meantime, an important resource and the pool of skilled labor will have dwindled to the point that rebuilding them will be extremely expensive and time-consuming. Teaching programs in remote sensing have declined and both professors and students are directing their efforts elsewhere.
- **Data quality.** The quality of the data over time needs to be assured to obtain the value of repetitive coverage. This is especially important for agriculture and forestry. Some respondents expressed concern that the consistency of the radiometric and geometric corrections, which are now carefully controlled by university and Government experts, may degrade under private operation. Still, it would be in the best interests of a U.S. private operator to maintain its data at a high level of quality because of competition with SPOT Image or other U.S. private companies.
- **Continuing university input.** Members of university remote-sensing programs fear that transfer to private hands will diminish the public-good aspects of land remote sensing and reduce their role in finding new and better ways to use the data.
- **Long term data trends.** Plotting potentially harmful changes on the Earth's surface requires data to be continuously available and safely stored for later retrieval. It also requires a research community with adequate resources. University researchers express concern that transfer to the private sector may mean a loss of data continuity, reduction in the quality and quantity of the archival material available, and reduction in Government support of research in this important area.

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[9] OTA Workshop on Remote Sensing, July 26, 1983.

*Corrected data are the raw data as received from the spacecraft, corrected only for radiometric and geometric distortion. This is the way the data are now sold in standard packages from the EROS Data Center.

USING HIGH-RESOLUTION DATA

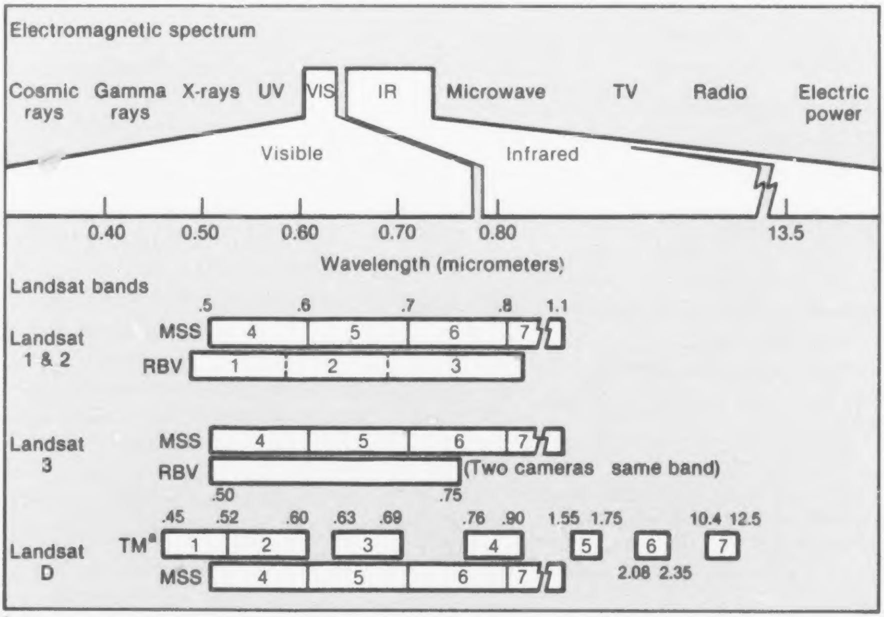
Thematic Mapper (TM)

Most research and applications projects using Landsat data have used MSS data having a nominal spatial resolution on the ground of 80 meters and four spectral bands. The TM, which is operated by NASA as a research instrument, has a much improved 30-meter spatial resolution and seven spectral bands. Studies with simulated TM data sensed from aircraft, as well as with some of the early TM data from outer space, indicate that this higher spatial resolution will enable major advances in the utility of such satellite data.

For example, NASA research suggests that in suburban areas land-use classification accuracies of 89 percent are possible. In urban areas, the potential accuracy is difficult to estimate before more detailed research is done.[10] Certain aspects of TM data have great promise. For tasks where spatial discrimination is important, such as mineral exploration, high resolution is the most obvious improvement over data from the MSS; other attributes of the system are equally remarkable from a technical standpoint. The TM digital data come in an eight-bit configuration which potentially will offer more information content than the six-bit configuration of the MSS data. In addition, the seventh spectral band is thermal which, when combined with the other six bands, can be expected to provide new interpretive capacity.

For agriculture, the real advantage of the TM derives from the narrowness of the spectral bands as well as their extension into the near infrared at 2.2 micrometers and thermal infrared at 11 micrometers. These attributes make the TM much more than a high-resolution MSS. Initial analyses of the TM data from U.S. agricultural areas show much sharper delineations of crops having different textures and tone. These observations suggest that TM data will be much more capable of sep-

Landsat Bands and Electromagnetic Spectrum Comparison


Electromagnetic spectrum
Cosmic rays
Gamma rays
X-rays
UV
VIS
IR
Microwave
TV
Radio
Electric power
Visible
Infrared
0.40
0.50
0.60
0.70
0.80
13.5
Wavelength (micrometers)
Landsat bands
.5
.6
.7
.8
1.1
Landsat 1 & 2
MSS
4
5
6
7
RBV
1
2
3
Landsat 3
MSS
4
5
6
7
RBV
(Two cameras same band)
.50
.75
.45
.52
.60
.63
.69
.76
.90
1.55
1.75
10.4
12.5
Landsat D
TM^a
1
2
3
4
5
6
7
MSS
4
5
6
7
2.08
2.35

aThematic mapper.

SOURCE: U.S. Geological Survey.

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[10] Dale A. Quattrochi, "Analysis of Landsat-Y Thematic Mapper Data for the Discrimination of Urban Features," *Decision Support Systems for Policy and Management*, Urban and Regional Information Systems Association Annual Conference, Atlanta, Ga., August 1983.

arating corn from soybeans and, perhaps, barley from spring wheat. The improved resolution also offers significant improvements in delineating drainage in and around agricultural areas.

For forestry, the major improvements provided by TM data will probably include increased accuracy of measuring areas occupied by different types of vegetation—a highly significant improvement for forestry applications (see, however, below). The additional detail in the Landsat data should enable more accurate analysis of the data as well—small forest stands, roads, streams, and other features not discernible on MSS images are clearly seen in TM data.

For petroleum geology, the improved spatial and spectral resolution of TM data have already proved their usefulness. Nonetheless, those who specialize in locating new sources of oil or other minerals have indicated that the ability to sense Earth in stereo would be more important to their industry than the increased number of spectral bands or higher resolution.[11]

As the case of forestry illustrates, in some situations different analysis techniques will be necessary effectively to utilize the increased spatial and spectral resolution of the TM data. A recent study[12] showed that with standard "per-pixel" classification techniques, as the spatial resolution of the pixels improves, the ability to classify forested areas with accuracy decreased significantly. Indeed, with data having 30-meter spatial resolution, overall classification performances were considerably poorer than with Landsat MSS data of much lower resolution. The use of 15-meter-resolution data resulted in a significant decrease in overall classification performance.

These results substantiated earlier studies[13] that found a similar decrease in classification performance with increasing spatial resolution primarily in areas of forest cover, but not in agricultural cover types. The reason is that images having higher spatial resolution allow more detailed spectral data to be obtained. Thus, in forested areas, the spectral response of one resolution element of TM data could be dominated by tree crown, whereas the adjacent resolution element could be dominated by the shadow area between tree crowns, and so forth. The coarser spatial resolution of Landsat MSS data averages such spectral differences, resulting in much less variability from one resolution element (pixel) to the next.

In agricultural areas, where the field size is larger than the 80-meters resolution of the MSS instrument, approximately the same percentage of row crop, bare soil, and shadow is being sensed and integrated into the spectral response of each resolution element, whether it be a 30- or 80-meter spatial resolution. To take full advantage of the higher spatial resolution of the TM data for forestry applications, therefore, the standard per-pixel methods of analysis must be replaced by finer methods using both the spectral and the spatial information of the data. This finding brings out three key points which apply as well to uses of TM data other than forestry:

1. Different disciplines may need to apply different analysis techniques in order to use the same type of land remote-sensing data (e.g. geologic analysis techniques often are significantly different from those used in agriculture).
2. Changes in sensor systems may cause such significant changes in the characteristics of

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[11] Michael T. Halbouty, statement on Civil Remote Sensing Systems before the Subcommittee on Space Science and Applications of the House Committee on Science and Technology, and the Subcommittee on Science, Technology, and Space of the Senate Committee on Commerce, Science, and Transportation (97th Cong.), July 22 and 23, 1981, pp. 213-232.

[12] R. M. Hoffer, M. E. Dean, D. K. Knowlton, and R. S. Latty, "Evaluation of SLAR and Simulated Thematic Mapper Data for Forest Cover Mapping Using Computer-Aided Analysis Techniques," LARS Technical Report 083182, Purdue University, West Lafayette, Ind., 1982.

[13] E. P. Kan and F. P. Weber, "The Ten Ecosystem Study: Landsat ADP Mapping of Forest and Rangeland in the United tates," Proceedings of the 12th International Symposium on Remote Sensing of Environment, Ann Arbor, Mich., 1978, pp. 1809-1825; F. G. Sadowski, W. A. Malila, and R. F. Nalepka, "Applications of MSS Systems to Natural Resource Inventories," Proceedings of the National Workshop on Integrated Inventories of Renewable Natural Resources, Rocky Mountain Forest and Range Experiment Station General Technical Report RM-55, USDA Forest Service, Fort Collins, Colo., 1978, pp. 248-256.

the data that entirely different analysis techniques must be developed and tested.

3. The sheer volume of data in a TM scene for seven spectral bands will limit their use. Research efforts should be directed to offering the ability to select a windowed array of data from anywhere in the scene; currently only a quarter subscene is available on special order from the EROS Data Center at Sioux Falls, S. Dak. Thus, if one wants to process a portion of Earth's surface located near the center of the four quarter-scenes, it is necessary to order a full scene.

So far, investigators have devoted relatively little attention to evaluating TM data other than studying the quality of the data received. Neither NASA or NOAA have conducted formal applications tests. Therefore, one can only speculate on the uses or value of TM data for forestry, agriculture, or even geologic applications.

The French SPOT System

The SPOT satellite, with its 20-meter resolution, three spectral bands, and ability to point the sensors, promises to provide coverage not available through the existing Landsat system. SPOT's pointability (i.e., the ability to obtain images at angles to the vertical) will enable repetitive coverage of transient phenomena.[14] To take one example, between April 13 and 18, 1979, the Pearl River Basin in Mississippi, rose to an unprecedented level of 43.5 ft and devastated Jackson, the State capital. Providing cloud cover did not interfere, if coverage comparable to SPOT's (e.g., pointability and resolution) could have been obtained on April 15, 16, or 17, estimations of damage and analysis of the event could have been greatly improved. Landsat 3, which was in use during the flood, passed over shortly before the torrential rains occurred and again just as the flood waters receded (an 18-day period).

The 20-meter resolution of SPOT data may not prove to be as valuable as its pointability because higher resolution data have a point of diminishing returns. The sheer volume of data resulting from such high resolution over a large study area can quickly overload the storage and data-handling capacities of most computer systems now processing Landsat data. This problem is faced already by analysts attempting to use the TM data. The fact that SPOT will use three bands, rather than the TM's seven, will ease the problem of handling data volume at the expense of losing important spectral information. In addition, the SPOT satellite will sense a narrower swath of Earth's surface. Each scene will be proportionately smaller, making the data handling problem easier per scene.*

SPOT has flown simulated missions in the United States, and the results of these will answer

The SPOT Satellite

Characteristics of the high resolution visible (HRV) instrument	Multispectral mode	Panchromatic mode
Spectral bands	0.50-0.59 μm 0.61-0.68 μm 0.79-0.89 μm	0.51-0.73 μm
Instrument field of view	4.13°	4.13°
Ground sampling interval (nadir viewing)	20 m × 20 m	10 m × 10 m
Number of pixels per line	3,000	6,000
Ground swath width (nadir viewing)	60 km	60 km
Pixel coding format	3 × 8 bits	6 bits DPCM[a]
Image data bit rate	25 M bits/s	25 M bits/s

[a] DPCM (digital pulse code modulator) is a mode of data compression that does not degrade the radiometric accuracy of the image data (256 grey levels).

SOURCE: SPOT Image.

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[14] W. G. Broome, Larry J. Warwick, and G. Weill, "SPOT Satellites: A Major New Information Source for Urban and Regional Environments," *Decision Support Systems for Policy and Management*, Urban and Regional Information Systems Association Annual Conference, Atlanta, Ga., August 1983.

*The SPOT sensor views a ground swath 60-km wide compared to a swath width of 185 km for Landsat.

many questions about its future application. Some State agencies and other public and private groups are interested in formatting SPOT data to use existing Landsat processing computer software. If totally new software is required, it will slow the use of SPOT data.

Comparison of SPOT and TM Data

It appears probable that the enhanced resolution of either TM or SPOT data would be of significant value for measurement, but how the seven channels of TM data will compare to the three channels of SPOT data is still a matter of conjecture.* The middle infrared portion of the spectrum (available only with TM data) should eventually prove invaluable for geologic and snow cover mapping purposes. For forestry applications, the differences between TM and SPOT data are not obvious. It would be surprising if the stereoscopic capability of SPOT data had any major advantages in forestry, unless topographic maps for the area of interest did not exist, a condition that is much more likely in developing countries than in the industrialized ones. As mentioned above, however, it should be highly useful to the geologists, and will also improve the ability of mapmakers to generate high-resolution topographic maps. The higher resolution of TM, SPOT, or future systems may eventually prove to be very useful in differentiating and categorizing different varieties and maturity of trees, which would allow better estimates of timber volume in a forest stand. It will also allow agriculturalists to estimate crop production better in countries where the average field size is significantly less than the 80-meter resolution of MSS data.

Investigators have frequently raised questions about the advantages of various data formats or types of data from future proposed instrument systems. Such questions clearly indicate the need for an effective, ongoing research program to provide guidance and direction in developing meaningful operational systems.

For operational uses, TM data will tend to be used in a sampled mode rather than as complete coverage. This may limit the sales of TM data once the newness wears off, even in the petromining industries where the data have received high praise. At over $4,000 per frame, even the petroleum exploration geologist will tend to look at narrow areas rather than broad ones.

Advances in technology, such as high spectral and spatial resolution sensors, when linked with on-board data processing and improved computer processing may aleviate some of the near-term problems investigators expect to experience in using high-resolution TM or SPOT data.

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*When data from the recent simulated SPOT flights are fully studied, it will be possible to compare the data from the two systems.

REMOTE-SENSING ARCHIVES

Data gathered from meteorological satellite observations are obviously useful for short-term weather predictions. Less well-known is their part in forecasting over periods of weeks, years, centuries i.e., in the long-term prediction of climate. As we learn more about the long term effects of such climatic effects as El Nino (see app. H) and increased atmospheric levels of carbon dioxide, the utility of satellite data for climate studies becomes apparent. The operational weather satellites make major contributions to the long-term global climate record kept by the National Climate Program within NOAA. It assembles these data and combines them with other satellite and terrestrial data from the Department of Defense, the Department of Energy, USDA, the National Science Foundation, and NASA to produce world climate models.

Through this program, the Government has developed the mechanism to assemble and store meteorological data to meet the research needs of climatologists and others who require historical data about the weather. These data are recognized as a national resource and are treated accordingly To continue the research on weather and climate, it will be important to continue to archive satellite data. Continuity of the format of the data stored in the archive is particularly important:

> The overriding requirement is for a continuous, intercomparable data record for a span of time that is climatologically significant . . . the longer the more valuable it is in determining the likelihood of "extreme" occurrences."[15]

For Landsat data, the EROS Data Center in Sioux Falls, S. Dak., maintains an archive containing most of the data it has received. Although the archive includes foreign scenes taken by Landsats 1, 2, and 3 when their recorders were operating, and some other foreign scenes acquired by special agreement with foreign ground stations, the vast majority of these data are domestic scenes. The EROS Data Center does not sell most foreign data, either current or historical. Normally, customers must purchase data acquired from foreign ground stations directly from the stations in question.

The expense of maintaining a complete archive of all the data ever received from the Landsat system is great; in fact, not all data are equally worth saving, and it would be helpful to purge the archive of certain scenes, such as those containing a high proportion of cloud cover and duplicate scenes. However, obtaining a complete set of cloud-free data for the entire world would be a worthy goal. Such a data set would be especially useful for mapping, land-use planning, mineral exploration, deforestation, and desertification. Because of lack of funds, this has not been done so far, although NOAA and NASA recognize the value of such an archive. One of the problems in setting up such a worldwide data set is that the various foreign ground stations use slightly different standards for data acquisition and storage: the data are not entirely comparable.

Whatever form the archive were to take, the Government would have to decide whether the limited archive maintained at the EROS Data Center would be transferred to the private sector and under what conditions. If the archive were transferred, safeguards to protect it from later deterioration or destruction should be instituted so that all interested parties would continue to have access to these data, at least, without copyright restrictions.

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[15] *Civilian Space Policy and Applications,* op. cit., p. 344.

Chapter 5

U.S. Government Needs for Remote-Sensing Data

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Chapter 5

U.S. Government Needs for Remote-Sensing Data

This chapter summarizes Federal requirements for Landsat and metsat data as they apply to individual agencies. A number of Government-sponsored studies based on the use of Landsat data have engendered optimism about the utility of space remote sensing for a wide range of resource survey, mapping, and environmental monitoring tasks. However, the results of such studies remain tentative because the Landsat system has not been optimally configured for operational use nor managed according to business-like principles. Questions persist in Government agencies about system continuity, data cost, and timely delivery.

FEDERAL METSAT DATA USERS AND THEIR MISSIONS

The largest Federal user of metsat data is, not surprisingly, the National Weather Service (NWS) in the National Oceanic and Atmospheric Administration (NOAA). Indeed, the agency responsible for operating the first weather satellites in the early 1960's was the National Earth Satellite Center, a part of the old Weather Bureau. It was not until a decade later that a separate satellite service (National Environmental Satellite Service—NESS, now National Environmental Satellite Data and Information Service—NESDIS) was established.

NOAA's mission is to explore, map, and chart the global ocean and its living resources; to manage, use, and conserve these resources; to describe, monitor, and predict conditions in the atmosphere, ocean, air, and space environment; to issue warnings against impending destructive natural events; to develop methods of environmental modification; and to assess the consequences of inadvertent environmental modification over several scales of time. The global scope of NOAA's mission makes metsat data valuable to the various agencies within NOAA. NWS makes widespread use of satellite data to improve its forecasts to aviators, farmers, fishermen, fruit growers, commercial shippers, sport boaters, recreationers, and just plain citizens.

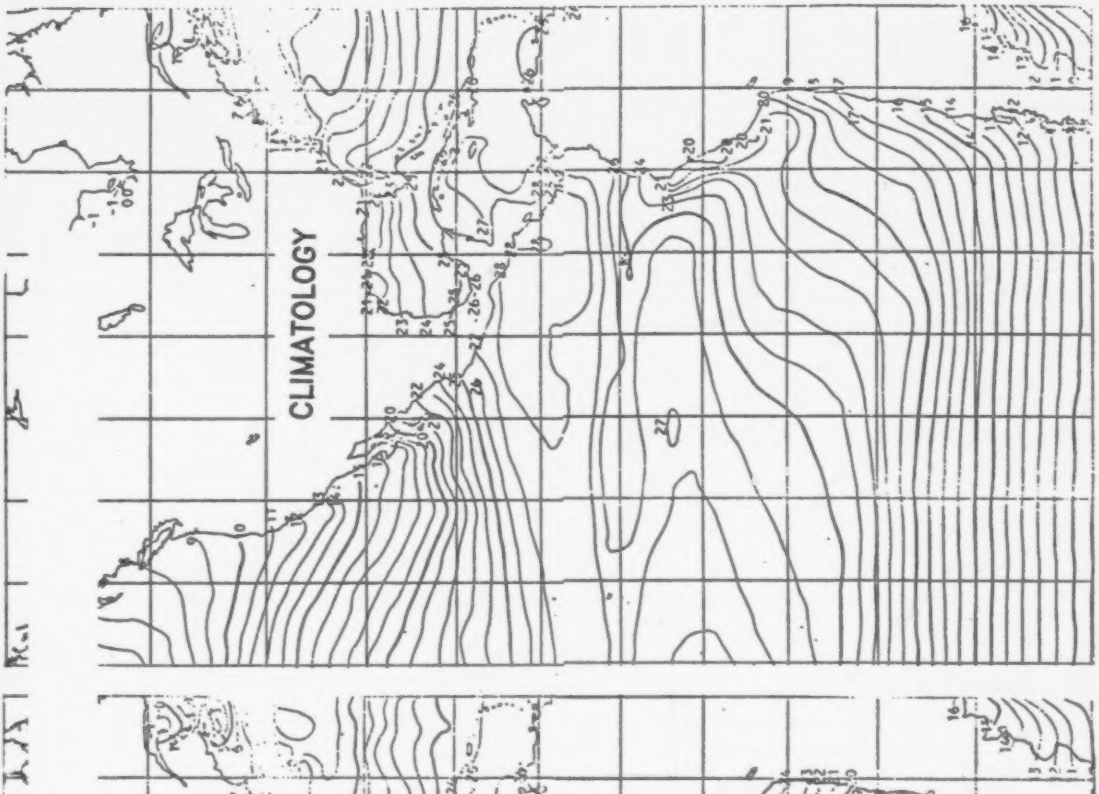
For example, the geostationary satellites can identify and track the characteristic cloud shapes of tornadoes, allowing warnings to affected areas. Hurricane tracking by satellite is a second vital lifesaver. The NWS Severe Storm Warning Center in Kansas City and the Hurricane Alert Center in Miami would both be severely handicapped without frequent satellite imagery to aid in issuing warnings.

The NWS Office of Hydrology produces river-basin snow maps and precipitation estimates for NESDIS to add to computerized hydrologic models for runoff and flood forecasting. Sounding data, sea-surface temperature data, cloud cover, and snow cover are but a few of the satellite-derived data that are processed by the NWS computers to improve global analysis and forecasting.

The powerful mixture of computers and satellites has produced new data sets that could well improve the ability of meteorologists to prepare longer range, even seasonal forecasts. NWS is now investigating sea-surface temperature changes or anomalies in the North Pacific and the percentage of snow cover in the Northern Hemisphere as important new variables in the study of climatic variations. Prior to metsats, these variables were unmeasurable (figs. 5 and 6).

The National Ocean Survey (NOS) explores, maps, and charts the oceans. The 1.1-km resolution of the polar-orbiting metsats is more than adequate to provide NOS with sea-surface temperature charts and ice charts of polar areas and the Great Lakes. NOS and NESDIS oceanograph-

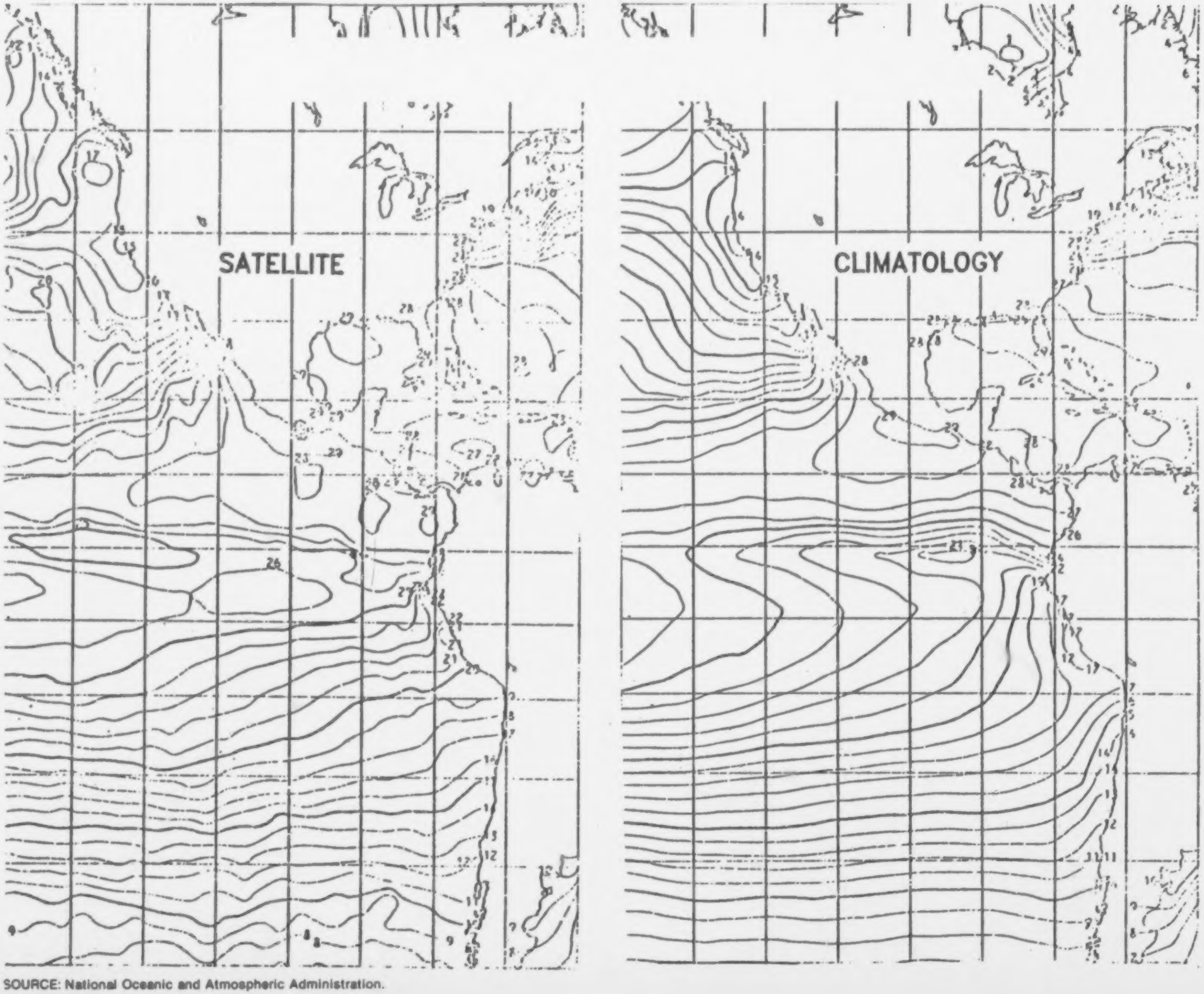
Figure 5.—April 1983 Sea-Surface Temperature, Eastern Pacific Ocean


SATELLITE
CLIMATOLOGY

SOURCE: National Oceanic and Atmospheric Administration.

BEST COPY AVAILABLE

Figure 6.—July 1983 Sea-Surface Temperature, Eastern Pacific Ocean


SATELLITE
CLIMATOLOGY

SOURCE: National Oceanic and Atmospheric Administration.

BEST COPY AVAILABLE

ers also chart currents using thermal infrared measurements. NOAA produces a monthly analysis of the Gulf Stream movements that aids in ship routing as well as in oceanographic research studies (fig. 7). It also uses satellite data to study the highly variable tidal and estuarine currents close to shore. It warns of tsunami from measurements collected by ocean buoys and relayed by satellite telecommunications.

The National Marine Fisheries Service has for many years used satellite thermal maps to indicate areas of nutrient-rich upwellings for commercial fisherman; such areas constitute the most probable good fishing areas.

Part of the National Climate Plan is to identify broad areas of environmental modification, whether manmade or natural. The results of prolonged drought, such as areas of desertification in the Sahel in Africa, are easily monitored by metsats. Metsat data can also be used to monitor the recent deforestation and development in Brazil's upper Amazon basin. The Department of Agriculture's (USDA) Foreign Agricultural Service (FAS) continuously monitors foreign crops using some NOAA polar-orbiter imagery in its efforts to project overseas markets for U.S. agricultural products. The Forest Service has found thermal infrared data from metsats useful for early detection of forest fires.

The need for up-to-date meteorological information is acutely felt by the Department of Defense (DOD) (see also ch. 6). Though many of its needs are met by the Defense Meteorological Satellite Program (DMSP), a system which includes two polar orbiters, DOD also relies heavily on NOAA satellites. The U.S. Air Force derives information from both the DMSP and NOAA's metsats to make flight weather summaries and forecasts; the U.S. Navy uses metsat data to monitor sea-surface temperature, currents, and water mass or ocean color, important variables for both surface and subsurface operations.

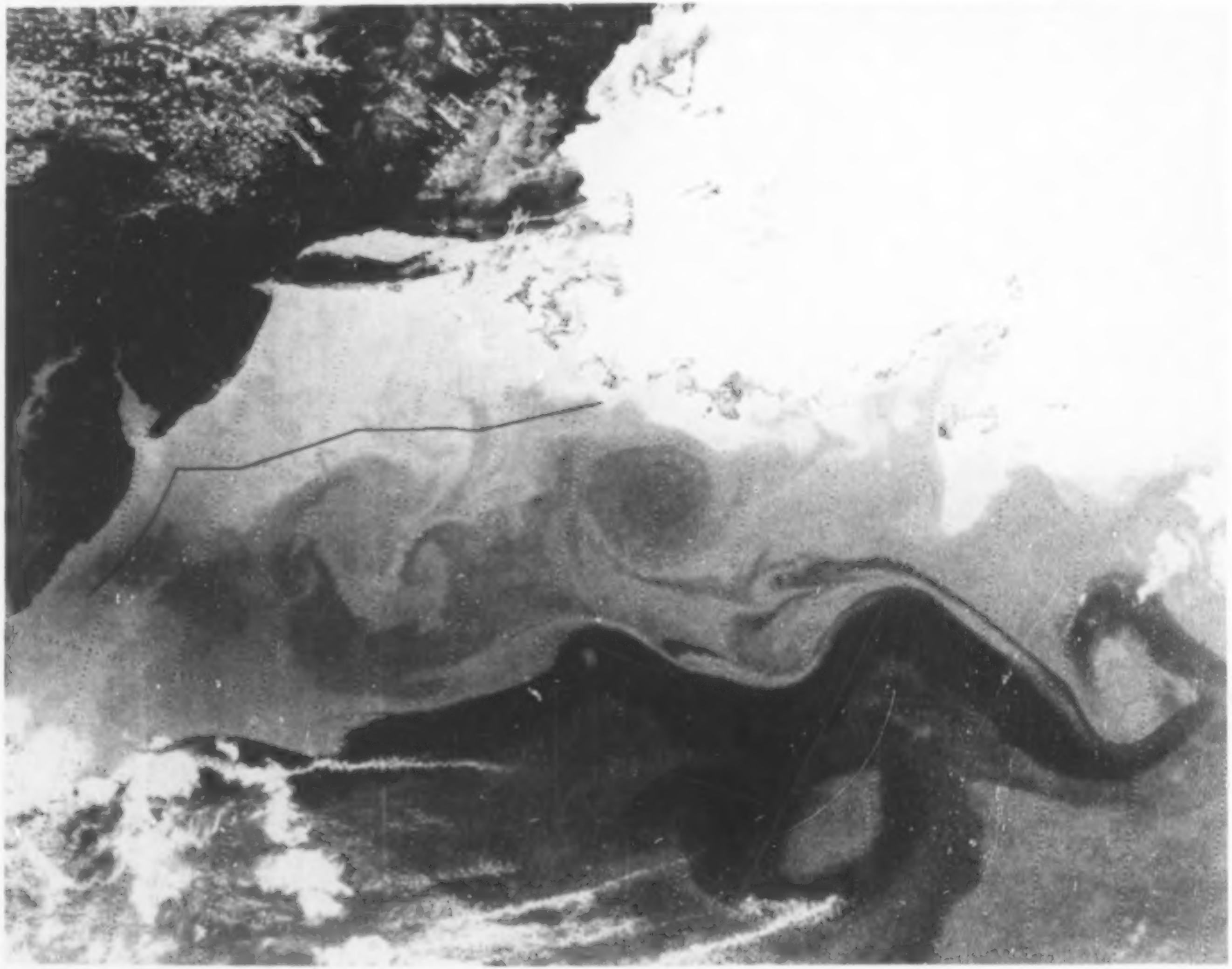
The mission of the U.S. Army Corps of Engineers includes programs to protect the environment, improve waterway navigation, control floods and beach erosion, engage in water-resources development, and provide natural disaster relief assistance. The Corps was an early user of metsat and Landsat data. Data Collection Platforms (DPCs), which relay data to the metsats, are widely used to provide operational hydrologic data to Corps offices. The New England Division of the Corps working with the Corps Cold Regions Research and Engineering Laboratory in Hanover, N.H., and the University of Connecticut, are determining the effectiveness of satellite imagery for real-time water-control management. The Corps Great Lakes Division has studied how to use data from space to improve their management of the Great Lakes water resources and navigation control.

The Office of Naval Research, the Naval Oceanographic Research and Development Activity, and the Naval Oceanographic Command, as well as DOD's Advanced Research Projects Agency, conduct, manage, and coordinate research in oceanography that requires metsat data.

The Department of the Interior is responsible for managing public lands and natural resources. A pilot program of monitoring vegetation in remote areas of Nevada and Arizona with data from the polar orbiters has been successful in the Bureau of Land Management's fight against range fires. This work was actually performed by the U.S. Geological Survey (USGS), which has a mandate to chart the Nation's water and mineral resources. Although the Landsat system is the preferred data source for some of the applications, especially hydrologic and tectonic studies, the USGS has increasingly turned to NOAA metsat data. The USGS's North American Tectonic Plate mosaic project is currently considering the use of enhanced images from the polar orbiters. It is also planning to make a mosaic tectonic map of Antarctica from enhanced metsat images.

In the Department of Energy, metsats furnish certain hydrologic information useful for the Power Administrations—e.g., Bonneville Power and Alaska Power. The Department of Transportation's U.S Coast Guard (USCG) has a direct obligation to provide search and rescue for ships in distress and to monitor the Contiguous Fisheries Zone. USCG icebreakers benefit from metsat observations of ice. The Coast Guard also uses metsat data to monitor oil spills, such as the Xtoc well in the Gulf of Mexico in 1979. Though it relies

Figure 7.—NOAA-7 Thermal IR Image of the Gulf Stream Meandering Eastward Toward Europe



SOURCE: National Oceanic and Atmospheric Administration.

The dark (warm) band is the Gulf Stream. Warm and cold eddies can also be seen on Government and private forecasters to advise pilots, the Federal Aviation Administration's (FAA) mission to regulate air commerce and to foster air safety requires that it consider all types of meteorological hazards and volcanic hazards as well; thus, metsat data are of direct interest to FAA.

The Environmental Protection Agency (EPA) has been charged with the responsibility to protect and enhance our environment. The EPA mission is to control and abate pollution from solid waste, noise, radiation, and toxic substances. Metsat data provide timely and frequent observations of air pollution such as windblown dust, oil spills, and nearby ocean currents, and trajectories for toxic or nuclear airborne pollutants based on satellite-derived wind vectors.

Many of these agencies have a continuing interest in following potential national disasters such as volcanic eruptions, floods, hurricanes, tornadoes, or earthquakes. The Federal Emergency Management Agency (FEMA) has the specific mission of enhancing emergency preparedness at Federal, State, and local levels to coordinate and oversee hazard mitigation, preparedness planning, relief operations, and recovery assistance. A recent study[1] found that although metsats, by virtue of their coarse resolutions, are not highly suitable for disaster management, they can be used by FEMA to detect the overall effects of drought and floods. Metsat data are a useful adjunct to Landsat data, which are more directly useful in disaster management.

NASA uses data from the metsats in its Earth Science and Applications Program. It also conducts research on improved sensors in partial support of the NOAA/NESDIS metsat program.

The U.S. Agency for International Development (AID) has provided assistance to developing countries in building their capacity to receive and use metsat data through programs like the Sahel Development Program, International Disaster Assistance, Food for Peace, and Science and Technology. Vegetation and hydrologic studies are also prepared by AID scientists using NOAA metsat data and imagery.

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[1] P. B. Richards, C. J. Robinov, D. R. Wiesnet, and M. S. Maxwell, "Recommended Satellite Imagery Capabilities for Disaster Management," proceedings of the 33d Congress International Astronomical Federation, Paris, September-October 1982.

FEDERAL LANDSAT DATA USERS AND THEIR MISSIONS

Landsat Data Purchases and Use by Federal Government Agencies

During the 1970's the National Aeronautics and Space Administration (NASA) was especially attentive and responsive to satisfying data needs of Federal agencies as part of its program to demonstrate the new technology, and transferred funds to potential user agencies for them to experiment with applying Landsat data to their missions. Because of the success of this close collaboration, some Federal agencies became major users of Landsat imagery and digital tapes. NASA followed the earlier precedent of the meteorological program in encouraging and stipulating open access to the satellite data. Yet, while the Earth imagery has proved effective for broad-area monitoring of events which affect private sector interests, such as oil spills, floods, the spread of insect infestation, and regional geology, many private companies continue to rely on the use of higher resolution aerial photography for commercial applications.

Over more than a decade of Landsat operation, the market for the data has grown slowly and Government agencies have not requested data at rates forecast by early studies. Nevertheless, a score or so of agencies have experimented with the data and several now have operational programs dependent on the application of space imagery. Direct Government data purchases from the EROS Data Center (EDC) account for between 20 to 30 percent of sales through 1982 (table 7). Sales information, however, is a poor indicator of actual data use, especially in the earlier, highly subsidized years. Some agencies used the data most extensively when they obtained them for free. Users have employed a variety of means to

Table 7.—Federal Government and Total Sales of Landsat Data by EROS Data Center and NOAA: 1973-83 (in thousands of dollars)

Fiscal year	Government sales	Total sales
1973	$ 63	$ 228
1974	87	528
1975	183	909
1976	594	1,641
1977	366	1,454
1978	610	1,976
1979	501	2,131
1980	393	2,389
1981	481	2,495
1982	572	2,941
1983	5,270 (1,188)	7,026[a] (2,934)

[a] Includes special acquisitions and service charges. The numbers in brackets indicate the sales excluding these special charges.

SOURCE: EROS Data Center, National Oceanic and Atmospheric Administration.

conceal or reduce the costs of acquisitions. Some were able to arrange for direct transmission of data to ground receivers, bypassing EDC completely.[*] In addition, agencies of both the Federal Government and various industry organizations have reproduced computer-compatible tapes (CCTs) (the most expensive items) and imagery and traded them among themselves. In the past year, as stricter accounting measures and control of data flow have been applied, overall dollar volume of sales to Federal agencies has increased dramatically. This change in procedures has resulted from an Office of Management and Budget (OMB) directive that system operating costs will be recovered by sales, and is a direct consequence of the shift from R&D to an operational system.

Current Level of Landsat Data Sales

Information on the sale of Landsat imagery and tapes is available from the authorized Government distributor, EDC at Sioux Falls, S.Dak., and from cooperating foreign ground stations. The January 1983 study of Landsat prepared by NOAA/ESDIS provides information through fiscal year 1982.[2] OTA has supplemented these figures by data extending through fiscal year 1983, obtained directly from EDC and NESDIS. Tables 7 through 12 and figures 8 through 10 express the sales information in a variety of ways and formats to make it as meaningful as possible. Federal purchases are shown, variously, in absolute dollar figures, as percentage of total sales, in number of items distributed, and as broken down among separate Government agencies.

Sales of Landsat data to Federal agencies have been negatively affected by two primary circumstances: 1) the present state of extreme uncertainty over the future of the Landsat program has effectively deterred Federal agencies from placing orders for future delivery of data to be used for satisfying mission data needs in cases where failure to receive the material on time would limit their ability to carry out their assignments, and 2) OMB has closely supervised purchases of Landsat data and required that money spent for this purpose by Government agencies be accompanied by a corresponding reduction in funds allocated for alternative methods of data collection. Agencies are often unwilling to give up older methods when they are unsure about their ability to receive Landsat data as needed. In addition, agencies that have need for only one frame of multispectral scanner (MSS) data for a given area have already satisfied most of their data needs; other agencies are simply waiting for thematic mapper (TM) data to be more widely available.

Overview of Landsat Data Sales

In contrast with the rapidly expanding market for the services of communications satellites, the market among Federal agencies for Landsat data has grown slowly. Thus, by fiscal year 1982, Federal purchases of Landsat data amounted to about $500,000 out of a total sales for all imagery of $3 million (table 7).[*] This difference in growth is explained by the fact that the communications industry was already well established and organized to use the new technology. For satellite communications, space technology replaced older terrestrial methods because it was cheaper or more efficient.

By contrast, data from the Landsat system presented unique and novel problems of handling, processing, and interpretation. In most cases they supplement other means of gathering data; in others, they present an entirely new data resource. The record of Landsat sales from 1973 through 1983 (table 8) reflects continuing, but decreasing, interest in the data on the part of Government agencies. During this period, Federal agencies tested these data for a wide range of possible applications to determine the potential advantages of switching away from conventional monitoring programs. NASA assisted the testing process by supplying data free to selected investigators (NASA Investigators in table 8), and in 1976 some 21 percent of all reimbursed data distribution was in this category. NASA broadened the base of trained people and stimulated the purchases of computers and other specialized equipment necessary to use the new material.

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[*] For example, for a period, the FAS received transmissions directly at its Houston receiving station.

[2] "Transfer of the Civil Operational Earth Observation Satellite to the Private Sector," U.S. Department of Commerce, February 1983.

[*] The more-than-doubled Federal sales in 1983 (bracketed figures) reflects the dramatic increase in 1983 prices over 1982 and the requirement that all Federal agencies must now pay for data.

Recent Trends in Landsat Product Sales

Expressed in terms of unit deliveries, sales of Landsat MSS data to all Federal users reveal a downward trend after 1978 and by key user agencies after 1980 (fig. 8). These trends can be attributed primarily to the decrease in funding for research in applying Landsat data, and price increases. In addition, the pace at which user agencies can marshal internal resources effectively to exploit the data is governed by OMB oversight and internal agency budgetary considerations. Some of the potentially large users of Landsat data are the resource survey and environmental agencies whose budgets have been most constrained during the recent period of fiscal austerity. In such times, managers find it more prudent to continue with well-known conventional monitoring systems (which, however, require more manpower) than to risk adopting new procedures based on a novel type of data requiring large capital costs for trained personnel and new processing equipment, especially when there is no guarantee of data continuity.

Experience with the Landsat data has demonstrated the superiority of computer-compatible digital products over Landsat photographic products for Government users as well as industrial purchasers. The inherent advantages of information acquired from space (e.g., its repetitive standardized format) are best exploited through selective manipulation of digital tapes.

Total income from Federal Government purchases for calendar year 1983 increased substantially over calendar year 1982 (tables 7, 8, and 9).* This jump can be attributed to two major factors: a nearly threefold price increase and the imposition of charges for special acquisition orders.** About 20 separate agencies of the Government are recorded as purchasers of the data, but most purchases are made by about a half dozen large data users.

Although income from data sales increased, the number of scenes delivered actually declined (table 10). The extent of decrease is not known since the deliveries to the FAS are not available. Special acquisition charges paid by both FAS and the Central Intelligence Agency (CIA) in order to assure scenes of specified areas at desired times and with minimal cloud cover, account for most of the increase in income. In the absence of purchases by these two agencies, Landsat data sales to Government agencies would have fallen dramatically.

The scale of Landsat data usage by FAS and CIA (table 11), appears to indicate that their applications have moved well beyond the experimental or demonstration phase into practical operations. For example, years of research with Landsat data have established its effectiveness in some types of crop forecasting. The importance to the national economy of accurate global crop data increases as the world's population increases with the world population growth and with a proportionate rise in U.S. exports of agricultural products. As an arm of USDA, FAS is charged with this function.

Sales data show a dropoff in use by agencies primarily concerned with domestic assessment and management. Direct interviews with Federal agency technical staff, however, temper any conclusions one may draw from inspecting only the

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*Figures in tables 9 and 10 cannot be compared directly to tables 7 and 8. The former are expressed in terms of calendar year, the latter in terms of fiscal year.

**Purchasers may stipulate cloud-free coverage of specified areas at specified dates by paying a surcharge.

Table 8.—Customer Profile of Landsat Total Data

Customer category	FY 1973[a]				FY 1974[a]				FY 1975			
	Items	Item (%)	Dollars	Dollar (%)	Items	Item (%)	Dollars	Dollar (%)	Items	Item (%)	Dollars	Dollar (%)
Federal Government (less N.I.'s)	21,780	27%	62,756	27%	28,493	18%	87,156	16%	34,346	17%	169,283	19%
NASA investigators	—	—	—	—	—	—	—	—	5,456	3%	15,992	2%
State/local government	2,995	4%	10,639	5%	2,534	2%	10,920	2%	1,969	1%	16,988	2%
Academic	13,071	16%	28,679	13%	18,611	12%	63,964	12%	27,727	14%	142,054	16%
Industrial	24,430	30%	67,360	30%	35,890	23%	114,140	22%	45,671	23%	219,704	24%
Individuals	5,109	6%	17,143	7%	17,266	11%	67,127	13%	18,643	9%	100,953	11%
Non-U.S.	8,497	11%	28,154	12%	37,038	23%	120,499	23%	47,174	24%	174,659	19%
Non-identified	5,189	6%	13,311	6%	17,346	11%	64,708	12%	17,397	9%	69,376	7%
Total data	81,071	100%	228,042	100%	157,178	100%	528,514	100%	198,383	100%	909,009	100%

Customer category	FY 1976				TQ 1976				FY 1977			
	Items	Item (%)	Dollars	Dollar (%)	Items	Item (%)	Dollars	Dollar (%)	Items	Item (%)	Dollars	Dollar (%)
Federal Government (less N.I.'s)	31,645	13%	253,166	15%	7,771	15%	73,436	16%	21,074	16%	269,825	19%
NASA investigators	63,329	25%	341,056	21%	5,730	11%	48,111	11%	9,827	7%	96,032	7%
State/local government	1,214	1%	8,191	0%	149	0%	1,168	0%	1,360	1%	20,168	1%
Academic	26,077	11%	178,160	11%	8,489	16%	40,129	9%	14,063	11%	141,077	10%
Industrial	42,833	17%	322,699	20%	12,122	24%	121,025	27%	36,979	28%	412,183	28%
Individuals	18,052	7%	141,556	9%	3,755	7%	28,683	6%	8,003	6%	72,129	5%
Non-U.S.	65,100	26%	391,673	24%	13,702	27%	138,632	31%	40,632	31%	442,079	30%
Non-identified	488	0%	4,892	0%	96	0%	1,087	0%	49	0%	344	0%
Total data	248,738	100%	1,641,393	100%	51,814	100%	452,271	100%	131,271	100%	1,453,837	100%

Table 8.—Customer Profile of Landsat Total Data—Continued

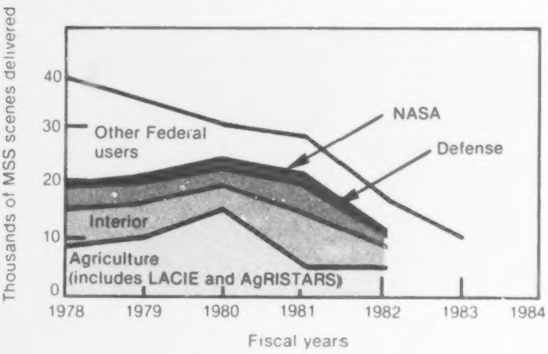
Customer category	FY 1978				FY 1979				FY 1980			
	Items	Item (%)	Dollars	Dollar (%)	Items	Item (%)	Dollars	Dollar (%)	Items	Item (%)	Dollars	Dollar (%)
Federal Government (less N.I.'s)	28,020	25%	597,269	30%	31,692	24%	501,214	23%	25,919	19%	392,591	16%
NASA investigators	522	0%	13,431	1%	0	0%	0	0%	0	0%	0	0%
State/local government	1,515	1%	31,557	1%	968	0%	19,281	1%	4,225	3%	78,327	3%
Academic	10,222	9%	159,379	8%	14,742	11%	235,231	11%	12,977	10%	202,401	9%
Industrial	21,321	19%	469,924	24%	25,903	19%	508,792	24%	24,723	19%	614,400	26%
Individuals	5,537	5%	73,808	4%	9,247	7%	102,854	5%	8,147	6%	96,982	4%
Non-U.S.	46,409	41%	630,700	32%	53,912	39%	764,441	36%	56,581	43%	1,003,866	42%
Total data	113,576	100%	1,976,068	100%	137,464	100%	2,131,813	100%	132,572	100%	2,388,567	100%

Customer category	FY 1981				FY 1982				FY 1983			
	Items	Item (%)	Dollars	Dollar (%)	Items	Item (%)	Dollars	Dollar (%)	Items	Item (%)	Dollars	Dollar (%)
Federal Government (less N.I.'s)	29,177	22%	481,067	19%	24,000	20%	571,807	20%	29,804[b]	47%	5,269,741[b]	75%
State/local government	3,470	3%	107,667	4%	5,251	4%	146,897	5%	1,268	2%	70,263	1%
Academic	11,401	9%	198,611	8%	7,753	7%	201,577	7%	2,536	4%	210,790	3%
Industrial	29,821	22%	758,245	31%	23,078	19%	924,540	31%	6,341	10%	632,369	9%
Individuals	9,292	7%	117,642	5%	5,953	5%	126,565	4%	1,902	3%	70,263	1%
Non-U.S.	49,965	37%	832,036	33%	53,964	45%	969,893	33%	21,560	34%	772,895	11%
Total data	133,126	100%	2,495,268	100%	119,999	100%	2,941,279	100%	63,413	100%	7,026,895	100%

[a] Landsat imagery only—no CCT customer profiles available for 1973 and 1974 (minimal data).
[b] Includes special acquisitions and acquisition charges.

SOURCE: National Oceanic and Atmospheric Administration.

Figure 8.—Deliveries of Landsat MSS Data to Federal Users by NASA-GSFC and DOI-EDC



NOTE: Breakdown of purchases by Federal users in fiscal year 1983 unavailable at present.

SOURCE: National Oceanic and Atmospheric Administration and Office of Technology Assessment.

sales evidence. The technical staff continue to see large potential benefits for their agency operations from the systematic application of Landsat data, if the system could be depended on to supply data dependably and promptly. The Bureau of Land Management (BLM), for example, has primary responsibility for monitoring vast tracts of western U.S. range and forest lands. The Denver Office of BLM made major investments in data-processing equipment in order to take advantage of the lower costs of Landsat data before prices rose and special acquisition surcharges were instituted. BLM currently is restrained in placing future orders for data because of insufficient funds and uncertainty over the future of the program.

Table 9.—U.S. Government Purchases of Landsat Data (in dollars)

Agency	CY 1982	CY 1983 (to 8-17-83)
Department of Commerce	$ 26,531	$ 14,006
Department of Agriculture (USDA)	100,101	70,986
USDA—Foreign Agricultural Service	N.A.	2,375,437[a]
Department of the Interior	402,232	181,016
National Aeronautics and Space Administration	55,967	29,108
Department of State (including AID)	11,682	380
Department of Defense	122,013	74,076
Central Intelligence Agency	41,435	1,390,650[a]
Other Federal agencies (12)	41,558	10,390
Total dollars	$801,519	$4,416,049

[a] Increased income in calendar year 1983 attributed largely to charges for special acqui[illegible], i.e., customer-stipulated area covered, timing, and condition of cloud cover.

SOURCE: EROS Data Center, National Oceanic and Atmospheric Administration.

Table 10.—U.S. Government Purchases in Number of Digital and Photographic Scenes

Agency	CY 1982		CY 1983 (to 8-17-83)	
	Digital	Photographic	Digital	Photographic
Department of Commerce	52	486	2	0
Department of Agriculture (USDA)	118	2,492	71	933
USDA—Foreign Agricultural Service[a]	N.A.	N.A.	N.A.	N.A.
Department of the Interior	1,038	13,314	121	2,059
National Aeronautics and Space Administration	128	682	28	602
Department of State (including AID)	5	325	0	5
Department of Defense	217	4,984	38	1,634
NSC/CIA[b]	7	433	0	5,293

[a] Acquisition charges of $2.4 million in calendar year 1983.
[b] Acquisition charges of $1.4 million in calendar year 1983.

SOURCE: EROS Data Center, National Oceanic and Atmospheric Administration.

Table 11.—U.S. Government Purchases of Landsat Data for Domestic and for Overseas Purposes (in dollars)

	CY 1982	CY 1983 (to 8-17-83)
Domestic agencies:		
Department of the Interior	$402,232	$ 181,016
Department of Agriculture	100,101	70,986
Department of Commerce	26,531	14,006
Total	$528,864	$ 266,008
Agencies with overseas responsibilities:		
Foreign Agricultural Service	N.A.	$2,375,437
Department of Defense	$122,013	74,076
Department of State (AID)[a]	11,682	380
NSC/CIA	41,435	1,390,650
Total	$175,130	$3,840,543

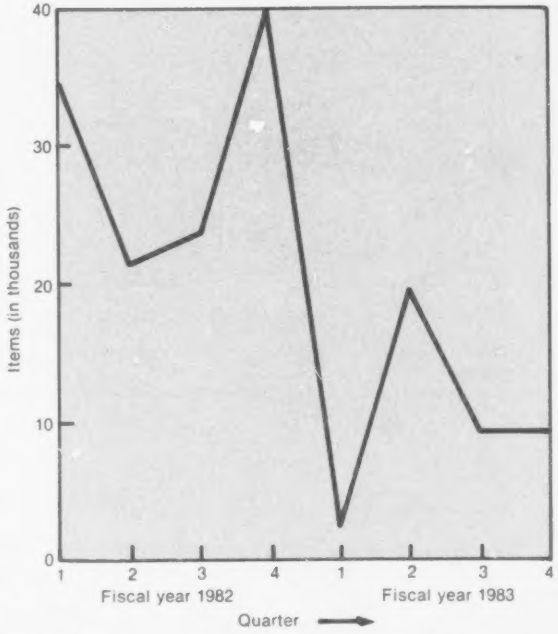
[a] AID stipulates use of Landsat imagery in many overseas contract areas not repeated within this table.

SOURCE: EROS Data Center, National Oceanic and Atmospheric Administration provided to OTA on Sept. 20, 1983.

While USDA is making operational use of the data, the Department is now paying for data that it previously received practically free through the Johnson Center for Manned Space Flight in Houston, Tex. The volume of data purchases reflects the agencies' ability to pay for them in the context of an overall budget. This, in turn, is attributed by some agency analysts to interventions by OMB which overrode agency desires.

Information on recent overall sales trends based on latest EDC reports as provided in table 8 is confirmed by detailed information supplied in the NOAA Landsat statistical summary for fiscal year 1982 and fiscal year 1983 (table 12 and figs. 10 and 11). Figure 11 shows that in terms of dollars spent, USGS and the category of non-Federal users have maintained a fairly constant dollar level of orders. The number of images and computer-compatible tapes purchased has decreased sharply for all purchasers outside of the Federal Government. For the first time, sales to Federal agencies have exceeded sales to the non-Federal U.S. community (table 8) and by a significant amount. This appears to be a result of the directive by OMB that each agency would account for its actual use of Landsat data, and therefore may not reflect a real trend.

Figure 9.—Quarterly Sales of MSS Imagery and Digital Frames (total sales, including non-Federal and foreign customers)



SOURCE: National Oceanic and Atmospheric Administration

Relationship Between Federal Users of Data and Agency Mission

The remote-sensing requirements of Federal agencies as well as State and local governments were examined in exhaustive detail by an interagency task force in 1978 and 1979.[3] Among other uses, the report served to help justify continued funding of the TM Landsat sensor.* Although it was not distributed beyond NASA and DOD, an unclassified section of the report listing the requirements for civilian agencies yields the data of figures 11 and 12. It states the requirements of eight Federal agencies as well as State and local uses, posed against a set of physical quantities or

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[3] Integrated Remote Sensing System Study (IRS³).

*TM development actually began in 1976.

Table 12.—NOAA Landsat Statistical Summary

	FY 1982 1st qtr.	FY 1982 2nd qtr.	FY 1982 3rd qtr.	FY 1982 4th qtr.	FY 1982 Total	FY 1983 1st qtr.	FY 1983 2nd qtr.	FY 1983 3rd qtr.	FY 1983 4th qtr.	FY 1983 Total
Frames in EDC data base[a]	1,689,792	1,721,991	1,738,971	1,768,542	1,768,542	1,810,565	1,835,689	1,863,857	1,891,002	1,891,002
Revenue[a]	$846,679	$593,970	$714,112	$818,484	$2,973,245	$245,244[d]	$1,718,937	$2,649,290	$2,412,850	$7,026,321[d]
Imagery	$430,096	$376,144	$400,034	$484,845	$1,691,119	$103,538	$ 444,685	$ 500,442	$ 577,347	$1,626,012
Digital	$391,100	$216,000	$312,070	$330,990	$1,250,160	$ 86,893	$ 241,205	$ 304,350	$ 235,080	$ 867,528
Accession aids	$ 25,483	$ 1,826	$ 2,008	$ 2,649	$ 31,966	$ 2,183	$ 1,349	$ 17,359	$ 1,126	$ 22,017
Other data[b]	N.A.	N.A.	N.A.	N.A.	N.A.	$ 52,630	$ 114,218	$ 113,509	$ 138,732	$ 419,089
Acquisition charges/cloud cover surcharges	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	$ 917,480	$1,713,630	$1,460,565	$4,091,574
Items shipped/acquisitions[a]	34,760	21,806	23,748	39,685	119,999	3,282	26,253	17,694	16,184	63,413
Imagery frames	32,927	21,055	22,649	38,394	115,025	2,394	19,460	9,324	9,125	40,303
Digital scenes	1,833	751	1,099	1,291	4,974	193	486	525	377	1,581
Other data items[b]	N.A.	N.A.	N.A.	N.A.	N.A.	695	1,859	1,572	1,578	5,704
Acquisitions	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	4,448	6,273	5,104	15,825
Customer contacts[c]	12,267	12,189	11,737	11,854	48,677	10,145	25,521	11,781	9,771	57,218
Orders received[c]	5,621	4,814	4,745	4,493	19,673	4,765	4,227	3,921	4,486	17,399

July-September 1983 data

Profile of total Landsat shipped sales (based on dollars)[e]		Type of Landsat business	
Federal Government	56%	Imagery B/W frames	60%
State/local government	4%	Imagery color frames	40%
Academic	4%		
Industrial	17%	Imagery B/W dollars	75%
Individuals	2%	Imagery color dollars	25%
Non-U.S.[f]	17%		

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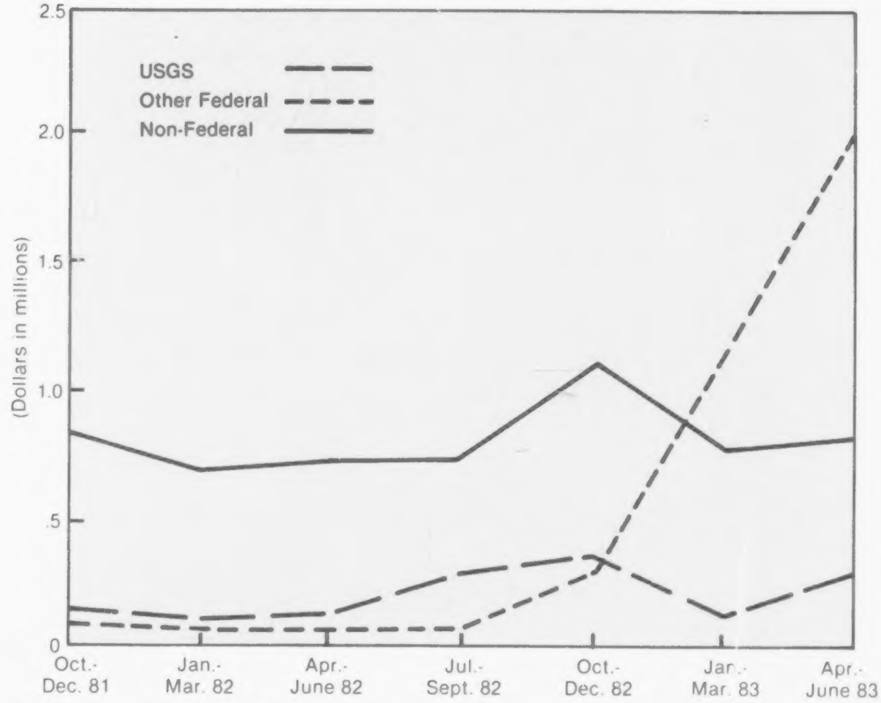
[a] Landsat only.
[b] Includes Landsat 4 MSS sample CCTs.
[c] Includes aircraft and other data.
[d] Excludes $1,112,239 carryover from fiscal year 1982.
[e] Excludes acquisition charges and cloud cover surcharges.
[f] Based on address, not geographic coverage.

SOURCE: National Oceanic and Atmospheric Administration.

Figure 10.—Grand Total of Shipped Sales From EROS Data Center in Dollars (mainly Landsat data but also includes other satellite imagery, aircraft imagery, and miscellaneous services)



SOURCE: EROS Data Center Product Summary Statements for seven quarters, 1982 and 1983

qualities that must be known in order to meet or satisfy agency missions or objectives. Of the 62 measurement classes listed, 43 can be met at least in part by the TM, or in some cases by the MSS. The numbers applied in the matrix of figure 12 are simple additions and do not reflect importance attached to one agency's mission over another's. They do tend to emphasize subjects of greater coincidence of interest.

Review of Department of the Interior Requirements

The Department of the Interior has maintained a special interest in land remote sensing. A study produced by Interior in partial response to the IRS interagency study contains a comprehensive listing of uses to which the data could be applied (table 13). Table 14 provides a summary list of the various Bureau data needs which can be met by remote sensing.

Survey of Relevant Legislation

The major assessment of desertification in the United States, prepared by an interagency task force, included a list of pertinent legislation (table 15) that requires periodic surveys and measurements. This list supplements information from an earlier study (table 16). Both lists reflect the increasing demands placed on Government agencies during the decade of the 1970's for types of information that can be appropriately satisfied by remote-sensing techniques.

Concerns of Federal Landsat Data Users

The apparent discrepancy between the present relatively modest level of Landsat data sales and

Figure 11.—Abilities of Current, Funded, and Future Systems to Meet Requirements, by Agency

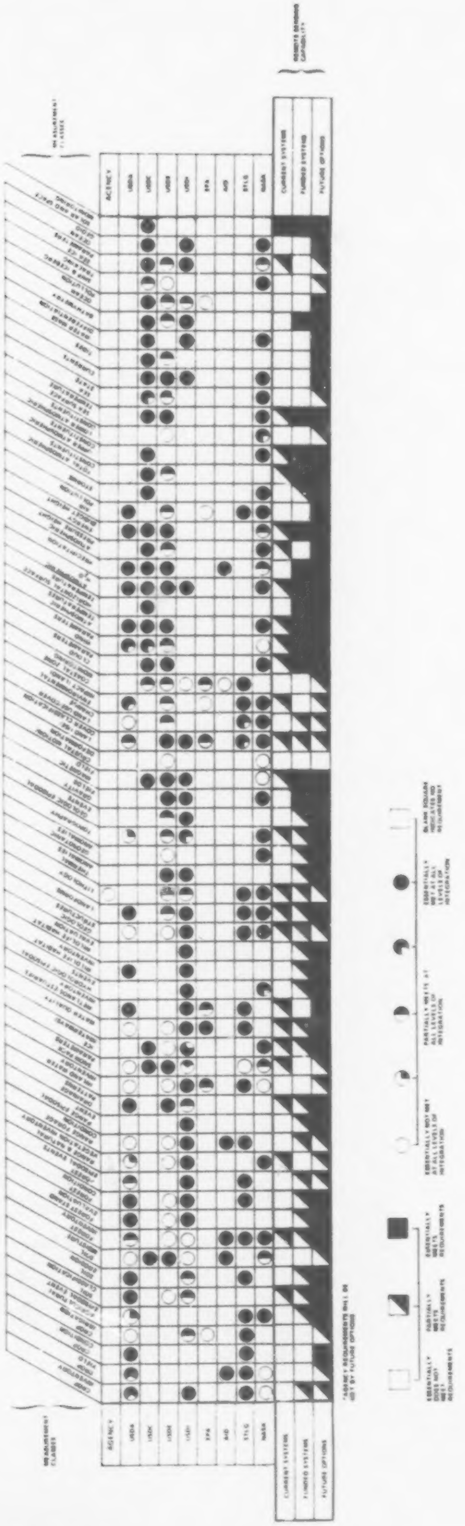


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Figure 12.—Number of Requirements in Each Measurement Class, by Civil Agency

AGENCY	CROP INVENTORY	CROP YIELD	CROP CONDITION	CROP IRRIGATION	AGRICULTURAL EPISODAL EVENT	SOIL CLASSIFICATION	SOIL EROSION	SOIL MOISTURE	FOREST INVENTORY	FOREST STAND EVALUATION	FOREST CONDITION	FOREST EPISODAL EVENTS	RANGE & NATURAL VEGETATION INVENTORY	RANGE FORAGE CONDITION	RANGE EPISODAL EVENT	DRAINAGE PATTERNS	INLAND WATER INVENTORY	SNOW PACK PARAMETERS	ICE (WATERWAYS)	WATER QUALITY	WETLANDS/ESTUARIES INVENTORY
USDA	12	13	7	11	5	10	10	12	11	7	7	7	9	7		5	5	7		3	12
USDC					2			4										9	25		
USDE					–			6	6	6	4		6	4		13	3	7		7	
USDI	1			4		29	7	9	74	17	16	2	73	17	2	23	7	3	3	20	6
EPA				1													2			6	2
AID		1						1	1					1							
STLG	2	1	2	1	2		1		5		1	1		1			10	1		1	1
NASA	2	2			3			2	1				1				1	4	2		

AGENCY	HYDROLOGIC EPISODAL EVENTS	WILDLIFE HABITAT INVENTORY	WILDLIFE HABITAT EVALUATION	GEOLOGIC STRUCTURES	LANDFORMS	LITHOLOGY	THERMAL ANOMALIES	GEOBOTANIC ANOMALIES	TOPOGRAPHY	GEOLOGIC EPISODAL EVENTS	GRAVITY FIELD	MAGNETIC FIELD	CRUSTAL MOTION/ DEFORMATION	LAND USE/ COVER CLASSIFICATION	LAND USE/COVER CHANGE	ENVIRONMENTAL IMPACT (LAND)	COASTAL ZONE MONITORING	CLOUD PARAMETERS	WIND PARAMETERS	ATMOSPHERIC TEMPERATURES	HORIZONTAL SURFACE TEMPERATURE
USDA		8		5	11				10					37	3	21			12	11	
USDC												1					7	30	28	17	6
USDE				15		7	3		7					7			3				
USDI	5	3	3	10	15	10	3		30		1	1		29			2				
EPA														8		12	2				
AID																	2				
STLG				1	1	1								9		2	1				
NASA	1			1	1	1		1	1		1	1	2	4		1		5	6	6	

AGENCY	ATMOSPHERIC H_2O	PRECIPITATION	ATMOSPHERIC PRESSURE	ENERGY BUDGET	AIR POLLUTION	STORMS	TOTAL ATMOSPHERIC CONSTITUENTS	UPPER ATMOSPHERIC CONSTITUENTS	LOWER ATMOSPHERIC CONSTITUENTS	SEA SURFACE TEMPERATURE	SEA STATE	CURRENTS	TIDES	WATER MASS DIFFERENTIATION	BATHYMETRY	OCEAN POLLUTION	SHIP & ICEBERG TRACKING	SEA ICE PARAMETERS	OCEAN GEOID	SOLAR AND SPACE MONITORING
USDA	9	15		11	6															
USDC	12	24	5	15		10	8	1		24	35	15	7	17	4	5	10	38	4	7
USDE	8			2							6	2					[illegible]	4	1	
USDI	1										1	1		1	3			4		
EPA					2											2				
AID		1																		
STLG					1															
NASA	7	3	1	9	5	2		3	4	2	2	2		1			1	4	1	

*Details of Analysis are in Appendices, Volume III. The numbers in the table are simply tabulations of the requirements submitted by the agencies. The relative importance of its requirements are not evaluated.

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Table 13.—Operational Uses That Can Be Implemented With Existing or Planned Satellite Technology

- Mapping geologic structure for mineral and fuel exploration (GS, BLM)
- Digital enhancement and analysis of altered and potentially mineralized zones and altered areas (GS, BLM)
- Monitoring seasonal consistencies and variations in the Beaufort OCS sea ice (BLM, GS)
- Regional environmental surveys for preparation of environmental impact statements (LBR, BLM, F&WS, GS, BIA, NPS)
- Detection and monitoring of surface mining and mine reclamation activities (OSM, F&WS, Mines, BLM, BIA, GS)
- Monitoring snow cover accumulation, melt, and change in irrigation and hydroelectric catchments in the Western United States and adjacent areas of Canada in order to contribute to predictive hydrologic models and runoff calculations (LBR, GS)
- Surface water inventory (LBR, F&WS, GS, BLM, BIA)
- Real-time analysis of mesoscale cloud systems (LBR)
- Water and wetland measurement to assess the amount and type of waterfowl habitat and the impact of irrigation (F&WS, LBR)
- Inventory of irrigated cropland, including acreage under irrigation and a breakdown by crop type (LBR, BIA)
- Mapping of flooded areas, estuaries, and shallow sea features (BLM, LBR, GS, BIA)
- Assessment of salinity problems in major watersheds (BLM, GS, LBR)
- Assessment and monitoring of physical water quality, water turbidity, and algae blooms (GS, F&WS, NPS, BLM, LBR)
- Monitoring ice conditions in Arctic goose nesting grounds to aid in the prediction of waterfowl populations. (F&WS)
- Vegetative cover mapping (BLM, F&WS, LBR, GS, BIA, NPS)
- Mapping extent of fire scars and rate of revegetation (BLM, F&WS, BIA, NPS)
- Contribute to land use/land cover mapping and land use/land cover change detection and statistical analysis of nonurban areas at scales of 1:250,000 and smaller (GS, NPS)
- Monitoring with Landsat to supplement and update orthophoto coverage of Indian lands (BIA)
- Mapping and classification of forest lands for the northwest Indian tribes to produce updated land-use plans (BIA)
- Publication of Landsat image maps at 1:250,000, 1:500,000, and 1:1,000,000-scale of unmapped or poorly mapped regions of Antarctica and other regions in support of national and international cooperative efforts (GS)
- Route selection for utility corridors (BLM, BPA)
- Monitoring ephemeral rangelands for drought and overgrazed conditions (BLM, BIA)
- Geographic positioning using doppler satellite (BLM, GS)
- Environmental data collection and relay (GS, NPS, BLM, LBR, F&WS, BIA)
- Teleconferencing and emergency communications (NPS, BLM, BIA, TA)

KEY:
BIA: Bureau of Indian Affairs
BLM: Bureau of Land Management
BPA: Bonneville Power Administration
F&WS: Fish and Wildlife Service
GS: Geological Survey
LBR: Bureau of Reclamation
NPS: National Park Service
OSM: Office of Surface Mining
TA: Territorial Affairs

SOURCE: U.S. Department of the Interior, *Secretary's Initiative: Use of Aerospace Technology*, Draft Mar. 30, 1978.

Table 14.—Current and Projected High-Priority Interior Applications Amenable to Landsat Technology

	Departmental activities					
Bureau applications	Onshore Energy and Minerals	Offshore Energy and Minerals	Water Resources	Land Resources	Fish and Wildlife	Telecommunications
Bureau of Reclamation:						
Water Management			X	X		X
Irrigated Land Inventory			X	X		
Agricultural Crop Inventory			X	X		
Hydrometeorological Data Relay			X			X
Mesoscale Cloud Analysis			X			X
Bureau of Land Management:						
Natural Resource Inventory	X	X	X	X	X	
Natural Resource Monitoring	X	X	X	X	X	X
Telecommunications Improvement						X
Geographic Positioning				X		
Fish and Wildlife Service:						
Migratory Bird Management			X	X	X	X
Habitat Inventory and Analysis			X	X	X	X
National Park Service:						
Vegetation/Land Cover Inventory				X		
Resource Condition Monitoring			X	X		X
Environmetal Quality Monitoring			X	X	X	X
Geological Survey:						
Land Cover Mapping			X	X		
Water Management			X	X		X
Cartographic Mapping	X		X	X		
Geologic and Mineral Assessment	X	X				X
Conservation and Regulation	X	X	X	X		X

SOURCE: U.S. Department of the Interior, *Use of Aerospace Technology in Interior Department Programs*, March 1978.

Table 15.—Existing Legislation Requiring Monitoring

Name	Reference	Agency	Data required
Mining Law of 1872	Public Law 42, Ch. 152	DOI	Develop mining resources of the United States
Desert Land Act 1977	Public Law 44, Ch. 107	DOI	Desert lands in certain States and territories
Carey Act of 1894	Public Law 53, Ch. 301	DOI	Reclamation of desert lands
National Irrigation Act of 1902	Public Law 57-161	DOI/USDA	Construction of irrigation works and land reclamation
Weeks Act of 1911	Public Law 61-435	DOI/ACE	Watershed and river navigability
Stock Raising Homestead Act of 1916	Public Law 64-290	DOI	Unappropriated Federal land to stock-raising
Mineral Leasing Act of 1920	Public Law 66-146	DOI	Promote mining of coal, oil, phosphate
Recration and Public Purposes Act of 1926	Public Law 69-386	DOI	Federal public lands to States and cities for recreational purposes
Fish and Wildlife Coordination Act of 1934	Public Law 73-121	DOI	Conservation of wildlife-fish games
Taylor Grazing Act of 1934	Public Law 73-482	DOI	Prevent injury to public grazing lands
Soil Conservation and Domestic Allowance Act of 1935	Public Law 74-46	USDA	Protection of lands against soil erosion
(and amendments of 1936)	Public Law 74-461	USDA	Protection of lands against soil erosion
Watershed Protection and Flood Prevention Act of 1954	Public Law 83-556	USDA	Works of improvement to prevent soil erosion
Multiple Mineral Development Act of 1954	Public Law 83-585	DOI	Multi-mineral mining of public lands
Great Plains Conservation Program Act of 1955	Public Law 84-1021	USDA	Great Plains Programs
Food and Agriculture Act of 1962	Public Law 87-703	USDA	Conservation of national resources
Clean Air Act of 1963	Public Law 88-206		
and Amendments of 1977	Public Law 95-05	EPA	Regional air pollution control locations
Wilderness Act of 1964	Public Law 95-05	DOI	Regional air pollution control programs
Land and Water Conservation Act of 1965	Public Law 88-578		
and Amendment of 1977	Public Law 95-42	DOI	Water conservation and outdoor recreation
Water Resources Planning Act of 1965	Public Law 89-90	DOI	Development of water and related land
Community Planning and Resource Development Soil Surveys of 1966	Public Law 89-560	USDA	Soil Survey Program
Wild and Scenic Rivers Act of 1968	Public Law 90-542	DOI	Preserve selected rivers
and Amendments of 1976	Public Law 94-486	DOI	
Endangered Species Act of 1973	Public Law 93-205	DOI	Preserve endangered fish and wildlife
Colorado River Basin Salinity Control Act of 1974	Public Law 93-320	DOI/ACE	Construction of public works on the river
Federal Land Policy and Management Act of 1976	Public Law 94-579	USDA/DOI	Public lands inventory
Water Bank Act of 1970	Public Law 91-559	DOI	Conservation of surface water
Mining and Mineral Policy of 1970	Public Law 91-631	DOI	Reclamation of mined land
Soil and Water Resources Conservation Act of 1977	Public Law 95-192	DOI	Further the conservation of water and related resources.
Clean Water Act of 1977	Public Law 95-217	DOI/USDA/ EPA/ACE	Improve biological integrity of the Nation's water
Endangered American Wilderness Act of 1978	Public Law 95-237	DOI	Protect wilderness preservation areas
Renewable Resource Extension Act of 1978	Public Law 95-306	USDA	Protect forest rain products
Surface Mining Act of 1977	Public Law 95-87	DOT	Protect society and environment from suface operations

Abbreviations: ACE — U.S. Army Corps of Engineers
USDA — U.S. Department of Agriculture
DOI — Department of the Interior
EPA — Environmental Protection Agency
DOT — Department of Transportation

SOURCE: Office of Technology Assessment.

Table 16.—Federal Statutes Pertinent to Remote Sensing

Name	Reference	Agency	Data requirements
Cotton Act	Public Law 92-331	USDA	Estimates of cotton crop and acreage
Bankhead-Jones Farm Tenant Act	7 USC 1010	USDA	Land inventory and monitoring of erosion, sediment, flood plain, land use
Agricultural Marketing Act	7 USC 1622	USDA	Statistics on agricultural product supplies
Halogeton Glomeratus Control Act	7 USC 1652	DOI/USDA	Surveys of presence and effect of *Halogeton Glomeratus*, a weed
Weather Bureau	15 USC 313	DOC	Enabling legislation
Soil Conservation Act	16 USC 590	USDA	Surveys and studies of soil erosion
Forest Pest Control Act	16 USC 594	USDA	Detection of forest insect pests on wildlife
Wildlife Protection	16 USC 665	DOI	Studies of effect of pollutants on wildlife
Fish and Wildlife Act	16 USC 742	DOI	Studies of fish and wildlife
Fishery Resources Act	16 USC 744	DOI	Studies of food, fish populations
Fish Resources	16 USC 758a	DOI	Studies of fish resources in South Pacific possessions
Fish Resources	16 USC 759	DOI	Studies of Atlantic coast shad
Fish Resources	10 USC	DOI	Studies of the Atlantic coast
Watershed Protection and Flood Protection Act	16 USC 100-1009	USDA/ACE	Investigations and surveys for flood prevention and watershed program development
Coal Mine Fire Safety Act	Public Law 83-738	DOI	Surveys and research outcrop and underground fires
Geological Survey	40 USC 641	DOI	Mineral exploration
Flood Control Act	Public Law 86-645	ACE	Identification of flood plain areas, damage assessment
Housing Act	Public Law 90-448	HUD	Technical assistance to local planning agencies
Bureau of Land Management	43 USC 2	DOI	Enabling legislation
Geological Survey	43 USC 31	DOI	Enabling legislation
Taylor Grazing Act	43 USC 315f	DOI	Land classification
Federal Reclamation Law	43 USC 485g	DOI	Land classification
Forest Resources Act	16 USC 581	USDA	Survey of forest supplies
Admission of New States	43 USC 857	DOI	Survey of public lands in a State prior to its admission to the Union
Land Use	43 USC 1181	DOI	Land classification and management
Outdoor Recreation Act	Public Law 88-29	DOI	Inventory of outdoor recreation resources
Food and Agriculture Act	Public Law 89-321	USDA	Commodity acreage and land use
Water Resources Planning Act	Public Law 89-80	DOI/USDA/ HEW/FPC	Studies of water supply adequacy
National Flood Insurance Act	Public Law 90-448	HUD	Establishment of flood risk zones, estimates of flood losses
Dam Safety Act	Public Law 92-367	ACE	Inspection of dams, Landsat data used to locate them
Federal Water Pollution Control Act	Public Law 92-500	EPA/DOC	Oil spill surveillance, violation detection, pollution surveys and research
Clean Air Act	—	EPA	Studies and detection of pollution
Hazardous Waste Management Act	NYP	EPA	Surveys of effects of hazardous wastes on the environment
Toxic Substance Control Act	NYP	DOI	Research and monitoring of extent of toxic substances
National Resources Land Management Act	NYP	DOI	Land inventory and land-use classifications
Land Use Policy and Planning Assistance Act	NYP	DOI	Comprehensive land-use planning
Marine Pollution Dumping Conservation	NYP	EPA	Monitor seas for pollution
National Environmental Policy Act	—	EPA	Environmental impact statements
Surface Mining Reclamation Act of 1973	NYP	DOI	Surveys of land-use and surface mining operations
Surface Mining Reclamation Act	NYP	DOI	Surface mining operations survey

Abbreviations: ACE — U.S. Army Corps of Engineers
USDA — U.S. Department of Agriculture
DOC — Department of Commerce
DOI — Department of the Interior
EPA — Environmental Protection Agency
FPC — Federal Power Commission
HEW — Department of Health, Education, and Welfare
HUD — Department of Housing and Urban Development
NYP — Not yet passed in 1974

SOURCE: General Electric, *Definition of Total Earth Resources System for the Shuttle Era*, vol. 1, NASA contract, 1974.

the need postulated in earlier official Government projections of demand is striking. In discussions with remote-sensing specialists from several Federal agencies the difference has been attributed to several technical and policy factors:

- Considerable modification in Landsat performance characteristics between Landsat 1 and Landsat 4, and the likelihood that future changes could seriously perturb the ways in which data must be processed in the future.
- Technical difficulties experienced in the Landsat 4 system.
- Initial slow production rate (one scene per day) of the improved resolution TM scanner. The X-band transmitter used to transmit data from the TM failed only a few months after launch.
- Delay in design and procurement of a more advanced solid-state and higher resolution scanner comparable to the scanner to be employed on the French SPOT spacecraft in 1985.
- Anticipation of a gap in data flow between the failure of Landsat 4 and launch of Landsat D′.
- Continuing delays in delivering data to customers.
- Uncertainty over Federal policy regarding a continuing role for a U.S. space remote-sensing system.
- The experimental phase of MSS is nearly over.

The Federal user community has generally concluded that experimental and demonstration projects carried out using the data products of the system have been successful in showing potential cost-effective applications to agency missions. These have included utility for a substantial number of national resource, environmental, and land management purposes. On the other hand, the Landsat system, they note, had not been run as an operational system until 1983. It has not provided the Federal user community with the assurances needed by managers of standardized data flow available over an extended period.

Chapter 6

National Security Needs and Issues

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Chapter 6

National Security Needs and Issues

INTRODUCTION

The U.S. Government operates two parallel programs of Earth remote sensing from space. Civilian systems operated by the National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA) provide unclassified low- and moderate-resolution information about the physical parameters of the Earth's land, water, and air. Department of Defense (DOD) classified satellites collect data for a variety of military and intelligence purposes such as early warning of missile attack, verification of compliance with international treaties, and strategic and tactical planning. While both programs may utilize similar spacecraft and basic technologies (e.g., earthward-looking sensors and ground processing), the programs differ in amount of funding, priority, and visibility.

The classified programs, among other things, provide essential data on activities in areas of the world where U.S. access may otherwise be greatly restricted. They are highly classified because they produce highly sensitive information, some of which could relate to ongoing classified military activities.* They are also highly classified because public knowledge of the capacities of the technology would be of considerable use to potential adversaries. Even nonsensitive data from the systems could, upon analysis, reveal the technical characteristics of the surveillance systems and compromise their effectiveness.

The prospect of transferring the civilian system to private ownership raises the question of what effects private ownership might have on the relationship between civilian and classified military remote-sensing systems and on the work of the military and intelligence communities. This chapter summarizes data and program support which civilian remote-sensing systems could provide to the military and intelligence communities and lists likely concerns of military and intelligence agencies over the prospect of transfer of civil activities from Federal ownership. It identifies requirements or conditions which it might be desirable to place on a private sector owner of a space remote-sensing system. Finally, it discusses the possible utility and availability for defense purposes of data from foreign space programs.

Meteorological Data

Data provided by civilian satellites operated by NOAA are an integral part of the DOD weather forecasting service. Since weather data are essential to the global operations of U.S. air and naval forces, a Defense Meteorological Satellite Program (DMSP) has been established to gather accurate, timely, and precise meteorological information. The DMSP is supplemented by the data products of NOAA meteorological satellites. Careful coordination between the programs from the design stage onward ensures that the family of polar-orbiting and geostationary satellites are integrated into a system for meeting both national civilian and military global weather data needs.

Weather satellites have proven particularly useful for obtaining data over oceans and remote areas where there is a paucity of surface reporting stations. In addition to determining atmospheric conditions on a near-instantaneous basis, the satellites contribute to observing slower acting phenomena such as ice-floe generation and climatic trends that could affect DOD's operations.

A recent NOAA study[1] states that any private system supplying meteorological data would be required to provide priority service to DOD and would be subject to DOD direction when selecting and designing operational parameters.

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*For many years, even "the fact of" the existence of strategic surveillance satellites was classified. Only in October 1978 was their existence officially acknowledged by an American President.

[1] "Transfer of the Civil Operational Earth Observation Satellites to the Private Sector," NOAA, February 1983.

Land Remote Sensing

The military and intelligence communities purchase the moderate-resolution Landsat data, in both imagery and digital tape format, to supplement collections made by classified systems.

The flexibility of the Landsat data receiving system has been increased by construction of an air-transportable ground receiving and data-processing unit, which permits rapid deployment to overseas sites, if required. This equipment could, in time of emergency, be used to supplement other data-collection means.*

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*The transportable station is also of use for general purposes.

CIVILIAN REMOTE SENSING AND NATIONAL SECURITY

So long as both the military and the civilian space programs are under the direct funding and management of the Federal Government, the activities of both can be readily coordinated and controlled in the overall national interest. Over the past two decades, policies governing the operations of unclassified civilian remote-sensing satellite programs have been developed at high levels of Government under the close supervision of the National Security Council. NASA, in collaboration with other Federal agencies, academic institutions, and industry, has carried on a substantial program of experimentation and demonstration which has served a variety of civilian and national security needs. DOD has pursued its own concurrent development program, which has returned some benefits to the civilian community.[2]

General policy governing the relationship between the national security and civilian space programs of the U.S. Government was established by the provisions of the National Aeronautics and Space Act of 1958. For reasons cited at the beginning of this chapter, details of the extent and nature of collaboration are not publicly available. Policies have been implemented through interagency agreements. The sharing of facilities and equipment, the setting of permissible limits for civil sensor operation, and many details on the acquisition and processing of data have been determined by Government policymakers, out of the public view. This has caused some discontent among some U.S. data users. However, the interest in commercializing the technology, and the simultaneous emergence of a number of competitive foreign space remote-sensing systems, require reevaluation of the intragovernmental arrangements and networks which have been used over the past decade for collaboration and control of remote-sensing programs.

Any transfer of U.S. civilian remote-sensing systems would be accompanied by a review of the obligations, conditions, and stipulations to be placed on the operator to protect national security interests. In some cases, such as control of technology transfer, existing regulations should serve to oversee adequately the operations of U.S. companies. The continued supply of data from civilian systems to defense organizations, similarly, should be a straightforward matter of adjustment to possible new price structures and delivery routes.

Military and intelligence agencies face other more difficult questions—e.g., the steps to be taken to preempt and operate commercial systems in time of national emergency. These and other safeguards, such as guarantees of the long-term availability of data, require both careful planning and commitment to some Government subsidy. Defense agencies can be expected to pay a proportionate share of the system costs incurred by a private satellite owner/operator to meet special Government needs.

A less tractable problem is to keep openly available data products of U.S. civilian systems from revealing classified information about the United States' sensitive installations and activities to potential adversaries. Since the Soviet Union possesses competent space reconnaissance systems, the problem really applies more to other potential adversaries, including those who might consider sponsoring terrorist activities on U.S. soil. Inclinations to set a limit on sensor resolution or to screen the data for content will run counter to the private entrepreneur's desire to maximize the information content of the data, shorten the time of delivery to customers, and generally to meet the competition posed by the advanced systems of France, Japan, and other countries. It appears that by the end of the decade, high-quality imagery and data on the entire surface of the globe will be generally available from foreign systems. This development will require accommodation among the sometimes conflicting aims of the U.S. military, political, and commercial sectors.

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[2] *Civilian Space Policy and Applications* (Washington, D.C.: U.S. Congress, Office of Technology Assessment Report, OTA-STI-177, June 1982.).

In the event of transfer of the Landsat system to private ownership, military and intelligence agencies will want to place certain limits on the design and use of the technology and the resulting data products. Though their special interests may be unique to this particular field of space activity, meeting defense limitations should require nothing beyond licensing and regulation. Principal areas of concern of the defense and intelligence agencies include:

- limits on technology and design criteria embodied in a civilian system;
- potential limits on day-to-day operations as they relate to sensitive contents, regions, or customers;
- impact of aggressive worldwide market development that may intrude upon national security needs; and
- policies on access and cost of data.

CONTRIBUTIONS OF THE CIVILIAN REMOTE-SENSING SYSTEMS TO MEETING NATIONAL SECURITY NEEDS

Under the terms of the National Aeronautic and Space Act of 1958, the Landsat and meteorological satellite systems must provide data that are not duplicated in their characteristics by any other U.S.-funded system, classified, or unclassified. This establishes a unique role for civilian systems in contributing to the net national pool of global land and meteorological information. Table 17 summarizes the contributions they have made. The Defense Mapping Agency has used Landsat data to revise hydrographic and aeronautical charts inexpensively. For example, the Landsat multispectral scanner (MSS) sensor is able to observe underwater detail, making possible a new class of shallow sea maps of interest to the U.S. Navy.

The MSS on Landsat scans continuously a swath of about 100 miles wide on the Earth's surface and rescans the same track every 16 days.* Thus, it has become possible economically to monitor vast areas in a routine way. Subsequent improved scanners like the multispectral linear array would have the same areal coverage with improved reliability and lower costs. Higher resolution sensors sacrifice the ability to cover such wide areas as cheaply because the number of picture elements increases as the square of the improvement in resolution. Although most human works or activities are not visible on MSS Landsat scenes, they are capable of revealing agricultural and other gross disturbances of the landscape. The higher resolution thematic mapper (TM) data, on the other hand, have rather good capacity to record the presence of human activity. Landsat data or their equivalent could signal the need for more detailed investigations of an area and, to some extent, guard against surprise developments in out-of-the-way parts of the globe, thereby freeing up more expensive and sophisticated surveillance systems to concentrate on areas of high priority.

The Landsat system, used in conjunction with meteorological satellites, has shown value in observing agricultural conditions and land-use patterns. Land degradation, population shifts, and other stressful conditions resulting from a combi-

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*Successful acquisition of Landsat images depends on the absence of cloud cover. Some regions of the world, especially tropical areas, are particularly hard to sense, even with repeated access.

Table 17.—Contributions of the Civilian Remote-Sensing Systems to U.S. Space Intelligence Systems

- **Complementary data:** The civilian metsat systems provide data complementary to those provided by the Defense Meteorological Satellite Program. U.S. intelligence and mapping organizations are substantial users of the unique data produced by Landsat to supplement other sources.
- **Backup system:** In the event of failure of a military or intelligence system, or a temporary overload, civilian metsat or Landsat data can be used instead.
- **Technical emergency support:** Landsat's worldwide network of communications, ground facilities, processing centers, etc., can, in an emergency, be used to support intelligence collections.
- **Broadened technical base:** A larger group of trained personnel and technical competence are available as needed.
- **Unique data products:** Information drawn from civilian sources, e.g., environmental monitoring information, can be used as a basis for further intelligence analysis.
- **Cover data:** Landsat imagery can be released and used as a basis for discussion involving the U.S. public or international forums, when the original source may be classified data which should not be compromised.
- **Political leverage:** Landsat and training can be used to extract reciprocal rights from foreign nations where intelligence operations may need base rights or special access.
- **General information needs:** Meteorological or Landsat technology helps to maintain cognizance of foreign remote-sensing developments by serving as the U.S. contribution at international technical symposia.
- **Political tool:** Open distribution of metsat and Landsat data has served to deflect and diffuse international criticism of U.S. space intelligence operations.

SOURCE: Office of Technology Assessment.

nation of environmental problems, population pressures, and political conditions, can contribute to instability and tensions and thereby may affect the overall security of the United States. Landsat data can be merged with data from other sources, including highly classified sources, to provide enhanced information on events in remote areas or regions where conventional information is scanty and unreliable. Some types of analysis, such as estimating foreign crop yields, can be made with Landsat data without necessarily revealing the precise areas of U.S. interest or requiring expensive collection activities.

Civilian/Military Interrelationships

The following paragraph items present a variety of examples of the types of relationship that DOD or intelligence agencies may wish to have with a private firm chartered to provide remote-sensing services. **This issue will be the degree to which a private owner will be able to assure direct support to Government activities, whenever these are requested by the Government.** These examples are intended to illustrate the range of potential applications, without attempting to evaluate their relative importance:

- **Provision of Primary Data in an Emergency.**—Earth-orbiting satellites are unique in their ability to view distant parts of the globe and relay the data back to the United States in near-real time.* Landsat and meteorological satellite systems also can serve as backup units in the event of a failure of one of the comparable classified satellites. In a national emergency, these civilian systems are subject to takeover by the defense forces. In the event of transfer of these systems to the private sector, it may be appropriate to require that data format and handling characteristics be compatible with military data management approaches.
- **Controlled Distribution of Data.**—Access to civilian remote-sensing data distribution channels and the ability to influence or control data flow can be of value to the intelligence and military communities. Analysis of sales records of land remote-sensing data may show patterns of foreign purchases, tipping off specific areas of interest for resource exploitation or military purposes, for example. In time of international stress, it might be desirable to delay or deny altogether distribution of land remote-sensing data to hostile countries if these data might be used directly against the United States or its allies.
- **Guarantee of Beneficial Data Exchange.**—The open, free distribution by the United States of meteorological data has created much good will and helped to develop patterns in which the United States benefited by receiving data in return from other countries. The U.S. lead in civilian space technology over two decades allowed the United States to gain acceptance of its right to operate in space and to sense other countries. Through the World Meteorological Organization and other international organizations, the United

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*When the Tracking Data Relay Satellite System is completed, it will be possible to send data from the spacecraft directly to the United States, no matter what part of the globe it is over.

States was able to advance the exchange of weather data worldwide to the benefit of many of its civilian activities as well as those of the military and intelligence agencies. This prompt and reliable supply of weather data from foreign sources is used extensively in air operations of the U.S. military. In addition, foreign data assist in ground-checking U.S. satellite data.

- **Use in International Meetings.**—The military and intelligence communities may, on occasion, be required to use classified data to assist U.S. civilian agencies in analyzing a major event for presentation in an international organization. An example might be fixing responsibility for damage from a large oil spill. In such a case, civilian imagery is obtained rapidly and presents objective information (e.g., Landsat data showed the extent of the recent Mexican oil well blowout as it affected the Texas coast). It can be used for multinational negotiations or for briefing the public without compromising more sensitive U.S. sources, if the event is sufficiently gross to be visible on Landsat imagery. As civilian instruments increase in resolving power, many more activities related to the security of nations could be revealed—troop activity in desert areas for example. The advantages and disadvantages for the United States of "open skies" and nondiscriminatory data distribution will have to be weighed. There is considerable value in having a source of open and unclassified data.

- **Continuing Source of Information on Foreign Space R&D.**—As the use of remote sensing becomes more widespread and the technology diffuses around the world, it will be increasingly important for military and intelligence agencies to be alert to new developments which can either be adopted and used for U.S. national security purposes or which, in the hands of others, could make the U.S. systems relatively less advanced. The maintenance of an open, advanced civilian program at all stages of development of satellite and remote-sensor instrument and data processing is necessary to preserving a broad technical base. Demonstrated U.S. competence in these fields assures that U.S. nationals will continue to be aware of technical advances at all stages and will be in a position to monitor developments of colleagues in other countries.
- **Civilian Program Hardware as Backup to Defense Programs.**—The command and control, communications, ground reception, and data-processing facilities needed for the civilian program are related to those used for classified remote-sensing programs. In the event of international tension, and by Presidential directive, civilian Government systems may be partially or wholly diverted to military use. To facilitate planning for such contingencies, the equipment used in civilian programs may have to be designed and constructed so as to be compatible with corresponding military components. Elements of the civilian system may also be preempted for interim backup service during, for example, the partial failure of a classified system.
- **Civilian Program Value in Providing Training and Special Skills.**—Trained personnel are a prerequisite for the management and operation of advanced technology remote-sensing programs at all levels, from equipment design, construction, and operation, to data reception, management, and interpretation. An open program helps to ensure a pool of trained personnel in each of these categories. Technically trained people constitute a pool of labor available to be drawn upon by classified programs as needed. Technical educational institutions must be operated on a largely unclassified basis and require the existence of a viable civilian program to attract students and to justify continued research and educational efforts.
- **Preferential Access to U.S. Data or Remote-Sensing Programs.**—As a new and somewhat glamorous technology combining space science and the potential for practical Earth applications, remote sensing has proven to be a means for entering negotiations with other countries. It is generally necessary to deal with foreign nationals on the basis of unclassified technology. In some cases, foreign governments stipulate the desire to deal with civilian agencies of the U.S. Government to

assure themselves of the high level and reliability of the exchanges. For example, the U.S. Geological Survey has been the prime instrument selected to manage mineral exploration by remote sensing in some Middle Eastern countries. On occasion this has resulted in finding mineral reserves that have national security implications.

- **Ability to Monitor and Influence the Course of Remote-Sensing Technology Transfer.**—U.S. civilian remote-sensing sponsorship and/or participation in international technical meetings enhances U.S. ability to observe and monitor closely the technological state of the art in foreign countries as a basis for judging the degree of technology transfer and determining whether such activities are to the net advantage of the United States, or should be inhibited.

POTENTIAL MILITARY AND INTELLIGENCE REQUIREMENTS

The military and intelligence agencies are by no means monolithic or uniform in their views of civilian remote sensing. Indeed, sometimes their individual goals conflict. Nevertheless, it is possible to summarize the possible requirements that various members of both communities have suggested if the proposed transfer of remote-sensing systems to private ownership proceeds:

- Continuity of meteorological data supply is an absolute necessity as a complement to military weather satellites. Orbital characteristics must be appropriate and sensors must perform as specified.
- It may be necessary to encrypt communications links and harden satellite components, or otherwise make the system conform to Government specifications on orbital parameters and sensor specifications.
- The operator must design the resolution and operating wavelength of sensors to meet military and intelligence restrictions.
- In dealings with foreign entities the operator will need to guard against unacceptable forms of technology transfer.
- Design and operations will need to take into account contingency planning requirements to assure compatibility and ability to operate in a possibly hostile environment.
- Operations will require that some private sector personnel possess special clearances and that secure facilities be available.
- Guarantees of specified types of operations with products conforming to agreed levels of quality, format, etc., may be necessary for 2 to 3 years in advance, as may guaranteed readiness of replacement satellites.
- The satellite operations may be subject to override or preemption in the event of national need, and the sale of product likewise may be "sanitized" or sales forbidden to certain foreign customers.

POSSIBLE SUITABILITY OF PROJECTED FOREIGN SYSTEMS

As discussed in chapter 3, within the next 5 years several foreign countries will possess remote-sensing satellites designed for a variety of land, ocean, and meteorological tasks. The U.S. military and intelligence remote-sensing communities can be expected to acquire and analyze quantities of data from these new systems for research purposes. To the extent that some unique kinds of information can be extracted from the data, it is possible that U.S. defense agencies may purchase some data sets for practical application.

On the one hand, continuing provision of specialized data from foreign systems, data impossible to obtain with U.S. satellites, might be advantageous to U.S. purposes. On the other hand, U.S. satellites, which collect and transmit global data back to U.S. collection points, have proven to be the most rapid and efficient means of accomplishing a host of sensitive national security operations because they can be tightly controlled. Information about both the surface areas and the time periods of interest to U.S. data collections must be controlled, because either would be of considerable interest to potential adversaries. Yet it is extremely difficult to control foreign sources, even systems operated by close allies, to the degree necessary. For most important satellite missions, the U.S. military and intelligence communities are likely to insist on totally in-house operations or the use of private U.S. contractors who can be regulated and closely supervised. Thus, it is unlikely that procurement arrangements would be worked out as part of the defense alliance agreement or that the material would constitute a primary source for U.S. forces.

Appendixes

Appendix A

Remote Sensing in the Developing Countries

Commercialization of Remote Sensing and U.S. International Relations*

Understanding the international effects of U.S. policy to transfer satellite remote-sensing systems to the private sector requires placing them in the context of 25 years of "space relations" as well as overall U.S.-developing country relations. U.S. actions with respect to outer space may affect negotiations over Law of the Sea, Trade, and other international areas. In addition, they must be placed in the context of overall U.S. foreign policy and policy towards the United Nations and other international organizations. Finally, they must be understood in the context of the perceptions of the foreign policy community, as distinct from the user community, in developing countries.

Historical Perspective and Developing Country Perceptions

The utilization of space has always raised political questions. However, initial discussions within the United Nations over rules governing outer space often found the United States and the U.S.S.R. on the same side. Neither desired international regulation of its space activities. The Outer Space Treaty formalized this point of view by allowing countries open access to space, with the caveat that no weapons of mass destruction would be placed in outer space, and the understanding that benefits from space-related activities would be used to the benefit of all countries, and particularly the developing countries. The political tradeoff between the two space powers and the developing countries during these early stages of space exploration was straightforward. In exchange for sharing of benefits and explicit promises that space would be reserved for peaceful purposes, there would be little international regulation.

Space applications, especially remote sensing, were first discussed in this context. The United States took the position in the U.N. Committee for the Peaceful Uses of Outer Space (COPUOS) that no international regulations were necessary for an experimental remote-sensing system (or any other space application), and promised that when the system was proven and became operational the developing world would share in its benefits. At the same time, the United States, while not directly supporting U.N. technical assistance, developed extensive bilateral agreements with, and technical assistance to, the developing world.

The developing countries have been particularly concerned about the possible use of satellite data by multinational companies to exploit the resources of developing countries. These countries have also expressed concern over the possibility that such data could be used for military purposes to the detriment of their own national security. Thus, they argued for restricted dissemination of the data and for technical assistance to aid them in developing their own ability to use them. These concerns, while mitigated to some extent in the mid-1970's, are still at the forefront of the international debate regarding remote-sensing satellites.

International negotiations to establish a regime to govern the distribution of remote-sensing data from space slowed to a near standstill early in the 1970's. The United States, for its part, was opposed to the establishment of any regime restricting the open development of satellite systems and the open dissemination of information. Many developing countries and the Eastern bloc countries, for their part, argued *for* regulating the distribution of remote-sensing data.

Over the course of these negotiations, the United States mitigated some concerns of the developing countries by disseminating data on a nondiscriminatory basis and by continuing its own technical assistance programs. However, as it became clear in the late 1970's that the United States was beginning to think in terms of an operational (and perhaps commercial) system, the position of the developing countries once again hardened, and the rhetoric of the debates became increasingly harsh. Ironically, one of the key concerns of the developing countries is that a commercial system might mean the end of open and nondiscriminatory access to data—the very policy they argued forcefully against for so many years. However, they see a policy of nondiscriminatory distribution as far better than one in which a U.S. company would own and control data acquired by remote-sensing satellites.

The issue of commercialization comes to the international arena in the context of over 100 years of international cooperation in forecasting and reporting the weather and 25 years of U.S. assurances that space would be developed for the benefit of all, particularly developing countries. It also must be seen in the context of 15 years of discussion regarding land remote sensing in which the United States has argued against regulation of remote-sensing satellites and has promised that remote-sensing data would continue to be available on an open, nondiscriminatory basis.

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*Based in part on discussions with Marvin Robinson, former chief of the Outer Space Affairs Division of the United Nations, fall 1983.

Interdependence

During the past decade, the nations of the world have become increasingly interdependent. This has affected international negotiations and organizations by creating linkages between issues which make it increasingly difficult to treat any issue in and of itself. Discussions on the distribution of satellite remote-sensing data carry over into the debate over such issues as direct broadcast satellites, the use of the geostationary orbit, the Law of the Sea, negotiations in the International Telecommunication Union regarding radiofrequencies, and the regulation of transborder data flows.

This tendency is compounded by the fact that in the developing countries, it is often the same individual who negotiates a wide range of issues. Hence, on a very personal, as well as substantive, level, what is said and done in one forum carries over into others. In understanding the broader ramifications of U.S. policy towards increased private sector involvement in space, one must consider not only remote sensing, but a broad range of other issues.

U.S. Foreign Policy Objectives

Delegates from some developing countries regard U.S. actions at the U.N. and in other international organizations as increasingly insensitive to the needs of developing countries. They suggest that the United States has missed excellent opportunities to generate good will and strength in international organizations.

The UNISPACE '82 conference, which was organized in part to discuss the potential benefits of space for the developing countries, was the latest example of U.S. policy in this area. The Department of State approached the conference from the perspective of limiting the damage to U.S. policies. In that, they were successful.[1] However, developing countries view the conference as a failure because it did not result in a plan of action.

According to some conference participants, the United States left them with the image of a nation unconcerned about the functioning of the U.N., pushing commercialization without consultation with the international community, and preparing to militarize space. Although these perceptions are not shared by all countries, they may well influence developing country activities in future international negotiations.

Although the issue of commercialization of satellite remote sensing appears of little consequence compared with the major troubles facing the world today, the development of space policy now depends on military policy, natural resources and economic development, and global environmental problems. In addition, as the national papers contributed to UNISPACE '82 illustrate, it is a highly visible arena upon which the developing countries have placed a tremendous amount of national prestige. As such, space cannot be seen as an issue of little consequence, even though it, in and of itself, may not be of the highest national priority.

Some developing countries view the commercialization of space as a hostile action because it removes the U.S. Government one step from its responsibility for U.S. actions in outer space. This ultimately may place the United States in a weakened position in the U.N. and other international forums.

Organizational Infrastructure

The ability of a country to adopt remote-sensing technology depends on its capacity to create appropriate institutions for its use and management. This is particularly at issue in the developing world, where space-related organizations have only recently emerged as part of the governmental institutions. Although there is no single best way to organize satellite remote-sensing programs, the successful adoption of the technology coincides with the development of a strong institutional infrastructure, including effective organization, equipment, and personnel.

Thailand[2]

The Royal Thai Survey Department, through the use of aerial photography, has benefited from remote-sensing technology for nearly 30 years. In 1971, the Royal Thai Government became aware of the possibility of using Landsat data to supplement its aerial survey data and joined the NASA-sponsored ERTS-1* international investigators.

Since that time, the United States has contributed to three U.S. Agency for International Development

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[1] *UNISPACE '82: A Context for International Cooperation and Competition—A Technical Memorandum* (Washington, D.C.: U.S. Congress, Office of Technology Assessment, OTA-TM-ISC-26, March 1983).

[2] Muscat, Craib, Ellefsen, and Willard, "USAID Assistance for Remote Sensing in Thailand: An Evaluation" (Washington, D.C.: USAID, June 1983).

*Later the name of this satellite system was changed to Landsat 1.

(AID) projects related to developing Thailand's capacity to use remote sensing from space. The first provided seed money for Thai scientists to undertake work in applications of remote-sensing technology. AID also funded a second ERTS program by providing some equipment and much training. Ten Thai's were trained in the United States and over 70 received training in Thailand. In the third project, AID funded the Remote Sensing Technology for Development Project, which concentrated more on building up equipment than on training. Since then, training programs have continued. The result is that hundreds of Thai scientists and technicians have now been exposed to the use of remote-sensing technology.

The primary institution for remote sensing in Thailand is the National Remote Sensing Program, which is housed within the National Research Council (NRC). NRC has recently been moved into the Ministry of Science, Technology and Energy after having been an independent agency. In this transfer, the remote-sensing program has been left intact. The National Remote Sensing Program makes up about half of the total NRC budget and continues to grow—particularly with the development of a ground receiving station. Its Remote Sensing Program is overseen by the National Remote Sensing Coordinating Committee, which consists of members from the primary user agencies in the Thai Government.

Figure A-1 illustrates the wide range of interest in remote sensing within the Thai Government. Twenty-three agencies are represented on the National Remote Sensing Coordinating Committee. Of those 23, 12 are active in providing or using remote-sensing data. At the same time, this chart shows the extent of international interest. Canada has now become the largest remote-sensing aid donor to Thailand, and the French are showing increasing interest in the Thai program. Remote sensing has clearly become a part of the Thai Government institutional structure.

Of major importance to the Thai National Remote Sensing Program was the construction of a ground station for receiving Landsat and metsat data. This ground station, built at a cost of over $10 million, represents Thailand's commitment to building technological as well as institutional infrastructure. This station has attracted much national attention and is a strong source of national pride. The Thai National Remote Sensing Program has also established brand-new building facilities at the site of the satellite ground station.

Other Thai Government agencies have also developed strong commitments to the use of satellite data. It is in these user agencies that the real payoff from remote-sensing technology comes. Without successful adoption of the technology within the user agencies, the institutional commitment to remote sensing in NRC will not help Thailand in its national planning.

In particular, the Royal Forestry Department, the Office of Agricultural Statistics, the Soils Science Division of the Department of Agriculture, the Royal Irrigation Department, and the Land Development Department have all made commitments of equipment and manpower to the use of satellite remote-sensing technology. For instance, within the Royal Forestry Department, Forest Mapping and Remote Sensing Subdivision, 20 people are directly involved with remote sensing—10 using aerial photography and 10 using satellite data. The latter have received training in the United States, at ITC/Netherlands, in Canada and at Thai NRC training programs. The Forestry Department's use of the data is limited by its equipment (which includes adequate visual interpretation equipment but not computer analysis equipment) and by the availability of satellite data. The Office of Agricultural Statistics has within it a Remote Sensing and Service Branch that is working on an Area Frame Sampling Program in which satellite data will play a minor role. Its commitment to Landsat data is less than that of the Forestry Department because it has found the data less useful. Within the Soils Science Division of the Department of Agriculture, three people are currently working with satellite remote-sensing data. In addition, eight to ten masters theses have been written applying satellite remote sensing to soils survey in Thailand.

The Thai Government user agencies, then, constitute the beginnings of an institutional infrastructure to support the use of satellite data. The use of those data is limited by the data themselves, slow data turnaround time,* and the lack of computer analysis equipment, as well as by organizational impediments.

These organizational impediments are the result, in part, of the manner in which the Thai Government has approached the organizational development of its remote-sensing program. Creating a separate entity within an existing institution separated the technology from institutions which have as their primary focus the solving of resource and environmental problems. Instead, it was housed in a service agency—and this generated problems in data availability and the application of satellite data by user agencies.

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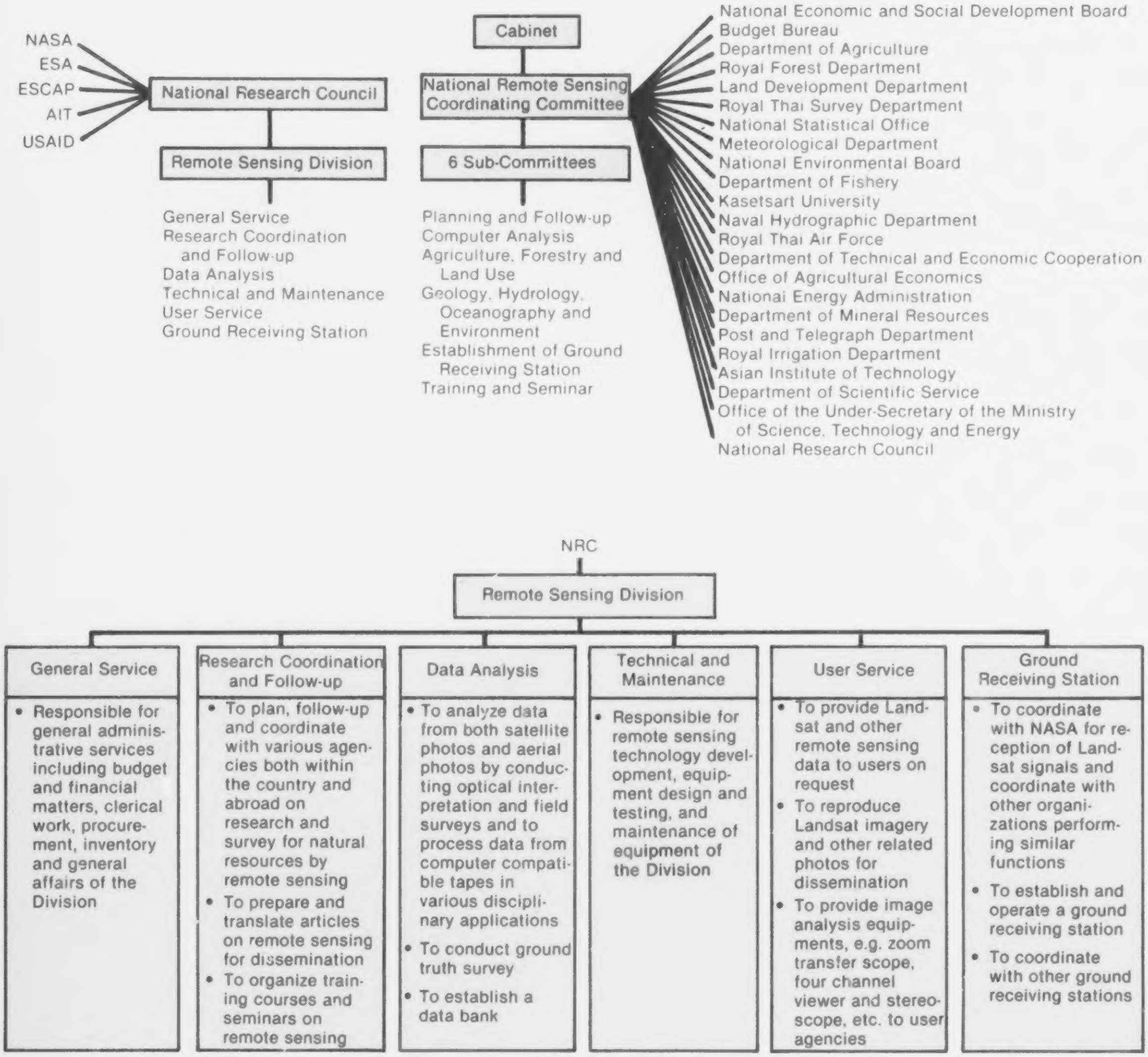
*The use of the data may be limited by the fact that they do not have high enough resolution for a specific application, by extensive cloud cover, or by technical problems which have occurred with the Landsat sensors. In addition, the data may not be available promptly enough for time-critical applications.

Figure A-1.—Organization of the Thailand National Remote Sensing Program


NASA
ESA
ESCAP
AIT
USAID
National Research Council
Remote Sensing Division
General Service
Research Coordination and Follow-up
Data Analysis
Technical and Maintenance
User Service
Ground Receiving Station
Cabinet
National Remote Sensing Coordinating Committee
6 Sub-Committees
Planning and Follow-up
Computer Analysis
Agriculture, Forestry and Land Use
Geology, Hydrology, Oceanography and Environment
Establishment of Ground Receiving Station
Training and Seminar
National Economic and Social Development Board
Budget Bureau
Department of Agriculture
Royal Forest Department
Land Development Department
Royal Thai Survey Department
National Statistical Office
Meteorological Department
National Environmental Board
Department of Fishery
Kasetsart University
Naval Hydrographic Department
Royal Thai Air Force
Department of Technical and Economic Cooperation
Office of Agricultural Economics
National Energy Administration
Department of Mineral Resources
Post and Telegraph Department
Royal Irrigation Department
Asian Institute of Technology
Department of Scientific Service
Office of the Under-Secretary of the Ministry of Science, Technology and Energy
National Research Council
NRC
Remote Sensing Division
General Service
Research Coordination and Follow-up
Data Analysis
Technical and Maintenance
User Service
Ground Receiving Station

General Service
- Responsible for general administrative services including budget and financial matters, clerical work, procurement, inventory and general affairs of the Division

Research Coordination and Follow-up
- To plan, follow-up and coordinate with various agencies both within the country and abroad on research and survey for natural resources by remote sensing
- To prepare and translate articles on remote sensing for dissemination
- To organize training courses and seminars on remote sensing

Data Analysis
- To analyze data from both satellite photos and aerial photos by conducting optical interpretation and field surveys and to process data from computer compatible tapes in various disciplinary applications
- To conduct ground truth survey
- To establish a data bank

Technical and Maintenance
- Responsible for remote sensing technology development, equipment design and testing, and maintenance of equipment of the Division

User Service
- To provide Landsat and other remote sensing data to users on request
- To reproduce Landsat imagery and other related photos for dissemination
- To provide image analysis equipments, e.g. zoom transfer scope, four channel viewer and stereoscope, etc. to user agencies

Ground Receiving Station
- To coordinate with NASA for reception of Landsat signals and coordinate with other organizations performing similar functions
- To establish and operate a ground receiving station
- To coordinate with other ground receiving stations

SOURCE: U.S. Agency for International Development.

Bangladesh[3]

The Bangladesh Landsat Program (BLP) was created in 1971, following Bangladesh's War of Independence, within the Science and Technology Division, Cabinet Secretariat. BLP was created as a multiuser program covering agriculture, forestry, land use, fisheries, water resources, etc., and was overseen by the National Landsat Committee of Bangladesh, an advisory group representing government user agencies, universities, and the Planning Commission. In addition, Bangladesh has a Landsat Task Force, consisting of over 30 investigators from user agencies, which works under the National Landsat Committee.

BLP recently merged with the Space and Atmospheric Research Center of the Bangladesh Atomic Energy Commission to form the Space Research and

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[3] "Space and Remote Sensing Activities in Bangladesh," SPARRSO, Bangladesh, 1980; and "National Paper: Bangladesh," UNISPACE '82, Vienna, June 1981.

Remote Sensing Organization (SPARRSO). This new entity is responsible for both research and operations for space science and remote-sensing technology in Bangladesh. SPARRSO currently operates an Automatic Picture Transmission (APT) meteorological ground station to receive signals from international weather satellites. With the aid of the United States and France, SPARRSO will soon be building a new ground-receiving facility capable of receiving both Landsat and SPOT data, as well as Advanced High Resolution Meteorological Satellite Data. Bangladesh has recently completed a new applications laboratory that contains visual and digital image-processing equipment, color and black-and-white photographic processing equipment, and photo-interpretation facilities. At the same time, the United States and SPARRSO have trained a nucleus of over 25 resource specialists in handling and interpreting satellite data. This training will continue under the upcoming U.S. and French programs.

The Department of Meteorology in Bangladesh is the government's weather forecasting agency. It integrates data accumulated by conventional methods with satellite data collected by SPARRSO. Most of the user agencies in Bangladesh use satellite data collected and disseminated by SPARRSO. In this way, SPARRSO has been and will continue to be a service organization for the rest of the government's user agencies. SPARRSO has attempted to avoid becoming isolated from the user agencies by bringing personnel from those agencies to work within SPARRSO. This approach seems to have been fairly successful in spreading the use of remote-sensing technology throughout Bangladesh. Bangladesh has developed a solid institutional commitment to the use of satellite data.

Kenya and Peru[4]

While both Bangladesh and Thailand have created new entities overseen by national coordinating committees to develop remote-sensing capabilities, they do not represent the only form of institutional development in the developing world. Both Kenya and Peru present examples of an alternative way of developing remote-sensing capabilities.

Kenya's initial interest in satellite remote sensing came from the Ministry of Natural Resources, which formed a national steering committee composed of representatives from agencies throughout the Kenyan Government. Until recently, however, no central focus for remote-sensing activities developed in Kenya, as primary responsibility for the new technology shifted from the Survey of Kenya to the Central Bureau of Statistics to the National Environment Secretariat to the Kenyan Rangeland and Ecological Monitoring Unit (KREMU). Outside funding of specific projects within each of these agencies caused these shifts of emphasis.

Today, KREMU functions as the national remote-sensing agency within Kenya. With a World Bank loan, KREMU is installing a digital processing system. This is a key step in Kenya's ability to use remote-sensing data, since up to this point Kenya has relied solely on visual analysis. This also marks a further, and substantial, commitment by Kenya to the continued use of satellite data. Kenya is studying the potential for establishing a regional remote-sensing center and ground facility in Nairobi. Intergovernmental coordination is the responsibility of the Committee on the Application of Satellite and Space Technology (COASST).

Kenya is also the host country for AID's Regional Remote Sensing Facility in Nairobi. This facility, serving the whole of East Africa, has benefited from the active participation of the Kenyan Government, which has cosponsored several training courses and symposia and helped to set up the center.

In addition to its work in land remote sensing, Kenya is actively using meteorological data from satellites. The Kenyan Meteorological Department receives APT images from the NOAA-6 polar-orbiting satellite, which it uses in determining cloud formation, type, location, and general cloud movement. The Department uses these data to map and monitor tropical cycles and to forecast hurricanes. Kenya hopes to improve its meteorological forecasting from satellite data, and plans to train more technicians in the near future.

Kenya is just beginning to develop an organizational context for incorporating remote-sensing technology into national planning. It is also securing the necessary equipment and personnel, a fundamental link in using remote-sensing data. Kenya has also shown a strong commitment to the use of remote-sensing technology through its participation in the African Remote Sensing Council and the AID regional training facility in Nairobi. More than 200 Kenyans have received training in satellite remote sensing and photo-interpretation techniques since the mid 1970's.

Kenya has taken a different approach to the development of remote-sensing capability than have either Thailand or Bangladesh. KREMU is not a space-oriented agency, but much more a user of satellite data and a provider of resource surveys to other Kenyan agencies. This type of organizational structure ties the use of satellite data more directly to actual resource and environmental problems, but it may make it more difficult to establish a focal point for remote-sensing activities. Nonetheless, Kenya's commitment to the future use of satellite remote-sensing data and the necessary manpower, equipment, and organizational infrastructure is strong.

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[4] "National Paper: Kenya," UNISPACE '82, Vienna, June 1981; and private discussions with Merrill Conitz, formerly head of the Regional Remote Sensing Program in Nairobi. The discussion of Peru is based on Campbell, Sader, and Ellefsen, "Land-Use Inventory and Environmental Planning Project: Peru" (Los Altos, Calif.: Resources Development Associates, April 1980); and "Remote Sensing for Resource Assessment and Management: An Evaluation" (Los Altos, Calif.: Resources Development Associates, 1979).

Peru, like Kenya, has placed responsibility for satellite remote sensing in a well-respected agency that will be a user of Landsat data and provide resource information to other Peruvian agencies. Like Kenya, Peru has chosen not to house its remote-sensing program in a special remote-sensing agency or a space agency, choosing instead to make it a part of an existing agency which sees the use of remote-sensing data as another tool for carrying out its mandated tasks.

Peru is now working with AID on a program to strengthen its infrastructure through institutional development, equipment purchases, and personnel training.

Other Programs

Several other developing countries have begun the institutional development necessary for the effective use of satellite remote-sensing data.

Egypt established the Egyptian Remote Sensing Center in 1971.[5] This center has become a focal point for remote-sensing expertise in the Middle East and North Africa. It employs more than 65 qualified/trained personnel and engages in cooperative work with many remote-sensing institutions worldwide. This center carries out its own research and is also supposed to coordinate remote-sensing activities within Egypt.

India has developed a strong national space program, with a large remote-sensing component.[6] Building on a strong organizational base and training program, India has established a full ground-receiving station and has plans to launch its own remote-sensing satellite in the near future. India's National Remote Sensing Agency is fully equipped with the latest in photographic and processing equipment. At least 65 of its employees were trained abroad in the United States and other industrialized countries.

In sum, then, whether the institutional commitment made by a developing country takes the form of a newly created remote-sensing/space organization or a newly created entity within an existing resource survey agency, it requires substantial commitment to developing institutional infrastructure.

The Use of Satellite Technology in Solving Environmental and Resource Problems

A great deal has been written about the application of satellite remote-sensing technology to the solution of environmental and resource problems of the developing world. Using examples from Thailand and Costa Rica, this section attempts to distinguish between potential and actual uses of satellite remote-sensing data.

Thailand[7]

Thailand has made numerous attempts to apply remote-sensing technology to the mapping and management of its natural resource areas. Some of these attempts have been remarkably successful and have led to operational use of the technology. Others provide good examples of innovative and adaptive use that may prove to be of significant value in the future. Still others have been complete failures.

- **Forestry.**—The deforestation problem in Thailand is severe. Each year an average of 4,650 square kilometers (km^2) of forest land is cut while only 800 km^2 are reforested, resulting in a net loss of 3,800 km^2 of forested land each year. At this rate of deforestation, Thailand would deplete its forests completely in the first quarter of the 21st century.

  The first indication of the extent of the deforestation problem came from a resource inventory done in 1973—the first year Landsat data were used to aid the Forestry Department. The results of the first full study utilizing Landsat data led to a more vigorous reforestation policy. The outcome of this policy is shown in figure A-2, which indicates an increase in the number of forest plantations throughout Thailand.

  Using Landsat data, the Forest Mapping and Remote Sensing Division of the Royal Thai Forestry Department has been able to map and summarize the status of forest lands nationwide every 3 years since 1973. Because of the high cost of aerial photography, this task would be impossible to accomplish without satellite data.

  In August of 1981, the Prime Minister's Office requested a report on the status of forest lands and deforestation throughout Thailand. The Forestry Department prepared this report using Landsat data. Since that time the Prime Minister has required reports every 3 months on the state of the forests in different parts of Thailand. The staff of the Prime

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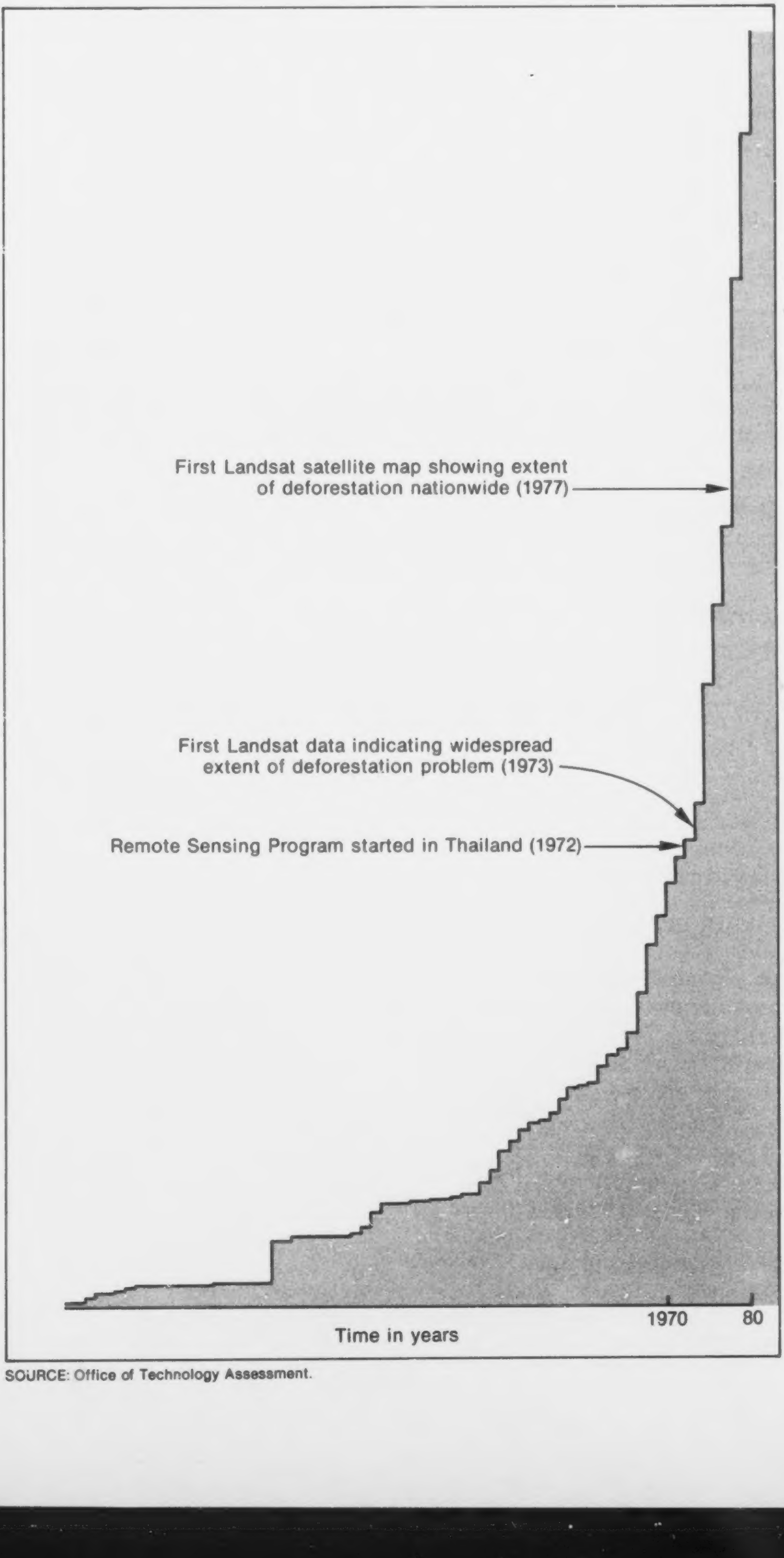
[5] "Remote Sensing of Natural Resources in Developing Countries: The Egyptian Experience," UNISPACE '82, Vienna, March 1981.

[6] "National Paper: India," UNISPACE '82, Vienna, May 1981.

[7] Muscat, Craib, Ellefsen and Willard, op. cit., June 1983.

Figure A-2.—Relative Number of Forest Plantations in Thailand



SOURCE: Office of Technology Assessment.

Minister then works with the Ministry of Agriculture and Cooperatives on agricultural development projects designed to settle farmers in already deforested areas rather than having those farmers move onto still-forested land.

Without Landsat data, Thailand would be unable to maintain an ongoing and up-to-date inventory of its forested lands and the level of deforestation. In fact, without the use of Landsat it is possible that the magnitude of the deforestation problem would not have come to the attention of decisionmakers in Thailand at all. This is one of the most dramatic examples of the successful use of Landsat data anywhere in the world.

- **Environmental Impact.**—Thailand has been less successful in using remote sensing to monitor the environmental impact of tin mining and offshore dredging near Phuket in southwestern Thailand. In 1980, the National Environmental Board started a program to monitor sedimentation, water pollution, and destruction of coral reefs in this area. The Environmental Remote Sensing Section has conducted extensive field-sampling surveys here, many timed to correspond with Landsat satellite passes over this area. They have also ordered satellite data over the Phuket region from September 1982 until the present. Unfortunately, although it is likely that the required information could be extracted from Landsat data, this project as been unsuccessful because the data have not been available from the Thai ground station or from the United States because of problems in the satellite sensor and tape recorders (of Landsat 3).

  Landsat data have been useful in evaluating the extent of soil erosion problems. One project, completed in 1982, identified several areas of severe erosion near the Pitsanuloke-Lomask Highway and in the Phumipol Dam Region. Some of these areas have lost upwards of 20 cm of topsoil on steep slopes. This study led to a bill, introduced in the Thai Parliament, to prohibit agriculture on steep slopes.
- **Crop Forecasting.**—Thai use of the Landsat system for agricultural crop production forecasting has not been nearly as useful as had been expected. Members of the Office of Agricultural Economics who have applied remote-sensing techniques to agricultural crop production forecasting believe that the technology is far from operational and that it is still in the research stage in Thailand. Impediments to using Landsat for crop yield forecasting in Thailand include:
  - —**Small field size.**—The practices of interspersing different crops on adjoining fields and planting adjoining fields with the same crops at different times makes it very difficult to use satellite data from the multispectral scanner (80-meter resolution).
  - —**Cloud cover.**—The presence of cloud cover during the growing season prevents substantial use of Landsat data.
  - —**Lack of timely delivery.**—In order to evaluate the state of the crops and take necessary remedial action, remote-sensing data need to be delivered within a few days.

  Still another difficulty with crop production forecasting is the lack of good yield models for crops in Thailand. It is necessary to predict both crop area and yield per acre.

  The failure to apply Landsat data effectively to agricultural crop production forecasting has been a major disappointment. Remote-sensing programs in many developing countries were justified on the expectation that they would improve agricultural forecasts. The fact that the enthusiasm for satellite remote sensing remains strong in developing countries despite the failure of Landsat with respect to agriculture, shows the strength of commitment of the developing world to the use of satellite data.

Costa Rica[8]

Costa Rica, like many developing countries, faces severe environmental and resource problems. It has experienced both rapid deforestation, as forest land is cleared to accommodate agricultural and grazing, and rapid urbanization, which destroys prime farmland.

Costa Rica is following a trend which is characteristic of all of Latin America. In 1978, Latin America was believed to possess 25 percent of the developing world's forest land area. If current trends continue, this forest area (around 550 million hectares) will be reduced by 40 percent. Most of the remaining forest will be found only in inaccessible areas. In Costa Rica alone, an estimated 50,000 to 60,000 hectares per year of forest land is destroyed, compared with a reforestation rate of only 1,000 hectares per year.

Although the Costa Rican Government was aware of these problems, it had not grasped their extent. In fact, during the 1960's and 1970's the Costa Rican Government did little to survey its resources. By the late 1970's Costa Rica realized that it needed a nationwide survey to define its current resource base and the rate of change of land use (either agricultural to urban or forested to grazing and agricultural) in the country.

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[8] "The Utility, Cost and Effectiveness of Remote Sensing for Forest and Urban Sector Assessment in Costa Rica" (Los Altos, Calif.: Resources Development Associates, March 1978); and "Design of a Natural Resources Inventory and Information System for Costa Rica: The Pilot Project Report" (Los Altos, Calif.: Resources Development Associates, June 1979).

In 1977, Costa Rica began an AID demonstration and pilot project to determine the feasibility of using Landsat to aid in a natural resources inventory for Costa Rica. The project was successful in confirming the magnitude of the resource and environmental problems facing Costa Rica—it created a clear picture of the rapid deforestation and rapid urbanization taking place in various "project areas" in the country. The study also showed the feasibility of integrating Landsat data into a national resources survey effort. In Costa Rica, even though Landsat data were used to illustrate the magnitude of a particular resource problem, and were shown to be a useful tool in monitoring that problem, the government did not follow up by undertaking a national survey.

Although Costa Rica has continued to use remote-sensing data, it has not adopted remote-sensing technology on the scale recommended by the studies. Two factors have brought this about: 1) there is no central institution in Costa Rica charged with remote-sensing responsibilities; and 2) in spite of the fact that each AID project had a strong training component, few trained personnel have afterward been able to devote their time to remote sensing. As the example of other developing countries has shown, the creation of a national advisory committee and the designation of a lead agency are clearly critical to the effective use of satellite data, even when the data are shown to be highly useful for monitoring serious environmental and resource problems.

Weather Satellites in Developing Countries

The flow of data from the weather satellites, rather than requiring the development of new institutions has been incorporated into the programs of existing weather agencies. The World Meteorological Organization (WMO) helped to provide the necessary receiving stations. Data have always been available at no cost.

Weather satellite data have been used for a multitude of routine tasks, from disaster and storm warnings to crop forecasting. Over $100 million has been invested worldwide in direct readout equipment and manpower, space processing, and dissemination equipment. At present, over 1,000 APT ground stations have been established in over 125 countries worldwide, including an extensive number in developing countries. Forty-four stations located in twenty-nine countries receive HRPT data.

These numbers are increasing all the time. The well-established weather-satellite user community in developing countries stands in marked contrast to the limited user community for land remote-sensing data. In fact, the "market" for Landsat data in developing countries is still in its developmental stages, primarily because the resource information programs of developing countries are only beginning to prove their worth.

Potential Effects of Commercialization

The transfer of all or part of U.S. space remote-sensing systems to the private sector would certainly affect the use of satellite data by the developing countries. The extent of its effects and how they are played out in political and scientific relationships will depend on several key factors: 1) the remote-sensing user community and the foreign policy community in the developing countries are separate, independent, entities; 2) regardless of U.S. policy in this area, France, Japan, and the European Space Agency are planning commercial remote-sensing ventures; 3) the market for remote-sensing data from space is in its early stages. While some users are clearly ready to integrate these data into their standard operations, others are still in the process of exploring the usefulness of remote-sensing data; 4) in the arena of foreign policy, the *perceptions* of Third World political leaders regarding transfer may be more important in determining their actions than the actual outcomes of comercialization on data users in developing countries.

The effects of transfer to private sector can be discussed in terms of five variables:

Data Type and Continuity

Development of a commercially operated Landsat system implies that all data would be available on a continuous and timely basis. If this were not the case, any commercial effort would fail. In fact, one could surmise that Landsat data would become available in a way which would compare to the current availability of metsat data. In isolation, such a development would clearly encourage the use of satellite data in the developing world.

One of the major complaints developing countries have made since the outset of the Landsat program has been that uncertainty over the future of Landsat has made it nearly impossible to develop the capacity successfully to incorporate remote-sensing data into national development planning. At the same time, the difficulty of receiving Landsat data promptly after a satellite pass has made it difficult to rely on such data. To the extent that ultimate commercialization of the Landsat system would mean the timely and continuous availability of data, it would greatly enhance the developing countries' use of satellite data.

In addition, it is likely that a private operator would also "tailor" its satellite sensors to its primary market areas. While the Government might well continue to perform R&D for advanced satellite sensors, the private sector would have to develop its own sensors in continuous interaction with the market. For instance, in the tropical areas of the developing world, a satellite sensor capable of penetrating cloud cover would greatly enhance the commercial value of remote-sensing data.* To the extent, then, that a private sector owner and operator would match satellite sensors to the needs of the market, commercialization would have a positive impact on the use of satellite data by developing countries.

Pricing

If the Landsat system is transferred to private hands, the price of data may well increase. Such a price increase, however, might have an adverse effect on the use of data and the further development of institutional infrastructure in developing countries.

This is not to say, however, that a price increase would eliminate the use of satellite data in developing countries. If the data were available promptly and continuously, then it is likely that developing countries would continue to use remote-sensing data to replace other, more expensive, means of obtaining resource information. Higher prices for satellite data would not necessarily discourage serious users of the data. They are more likely to discourage those users who are in the early stages of adopting remote-sensing technology, which would inhibit the growth of the market.

U.S. technical assistance programs have, for the past 15 years, helped developing countries adopt remote-sensing technology. If the U.S. Government wished to continue its technical assistance programs for satellite remote sensing, and thereby decrease the negative effects of a price increase, it could subsidize the cost of commercial remote-sensing data in its development projects.

In addition, a private company might well provide some incentives to developing countries to encourage them to use remote-sensing data. Many computer companies donate computers to developing country institutions to promote their products. There is no reason to think that the private sector would not operate in a like manner to develop a remote-sensing market.

Copyright and Data Protection Laws

Another key set of issues tied up with the transfer of remote-sensing data are those of copyright, proprietary data rights and data protection laws. Commercial interests generally want private ownership of data, thereby making the data a scarce resource for which the customer would pay more. As such, a commercial venture is likely to require data protection guarantees or proprietary rights to data. This is in line with traditional notions of private ownership, but goes against public notions of open access to information.

This is a key point in the entire commercialization discussion. It is clear that if a private firm, and particularly a multinational firm, were allowed proprietary rights to data acquired by satellite, many countries of the world—including the developing countries—would react negatively.

Government Technology Transfer and Technical Assistance Programs

In order to achieve success in commercializing remote-sensing technology, the U.S. Government will have to stop competing with the private sector in offering value-added services. Although they have been instrumental in spreading understanding and use of remote-sensing technology throughout the world, technical assistance and technology transfer programs may compete with the private sector.

Ever since the opening of the international debate over the future of remote sensing the United States has offered technical assistance to the developing world. This has helped to mitigate international concern over the U.S. policy of open dissemination of satellite data. If the United States were to stop providing technical assistance completely, the international debate over data dissemination might become more heated.

The U.S. technical assistance programs are largely responsible for the development of the international user community. To the extent that any market for remote-sensing data exists internationally, it exists because of U.S. aid. Discontinuing this aid would slow the further spread of land remote-sensing technology.

In attempting to provide technical assistance to developing countries U.S. policymakers will have to consider carefully the effects of their policies on the U.S. private sector. It may not be appropriate to discontinue technical assistance programs, but if the transfer is to be successful the Government will likely have to implement them at the market price for data and value-added services. As part of their marketing strategies, private sector operators might find it in their interest to assist developing countries in the use of the technology. Hence, transferring land remote sensing to private ownership would not necessarily mean an end to technical assistance, sponsored either by government or by the private sector.

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*Recently the Netherlands and Indonesia have explored the possibility of building a satellite system specifically designed for use over tropical regions.

U.S. Regulation

Several forms of regulation might be used to ensure that a commercial entity would conform to U.S. foreign policy objectives. These include such things as a guarantee of open access to data, much as they are available now from the EROS Data Center, or assuring a particular country access to data collected over its own territory. Other regulations might involve pricing regulations, guarantees of technical assistance and data continuity, etc. These types of regulations would have a positive influence on the use of satellite data by developing countries—however, they might discourage private sector commercialization efforts.

Appendix B

The Use of Landsat Data in State Information Systems

Computers have revolutionized the way States manage statistical, demographic, and natural resource data. Because they are acquired in digital form, data from the Landsat system have been particularly appropriate for inclusion in broad-based information systems. Early research efforts were directed primarily to producing land cover maps from Landsat digital data. These land cover maps were generally used as the single source for resource management analysis.

Geographic Information Systems in State Government

The Landsat system has the promise of providing up-to-date, low-priced, land cover data. In the 1970's, many States and universities, with assistance from the National Aeronautics and Space Administration (NASA), began to purchase specialized hardware that could support NASA's software for Landsat data processing.

With the publishing of Ian McHarg's book *Design With Nature*,[1] State and local governments began applying multiple data sources and multiple disciplinary approaches to resource analysis. McHarg advocated the use of hand-drawn overlays depicting a particular element (as defined by a particular specialist) affecting the suitability of area for a particular use. This overlay system, McHarg recognized, would eventually be computer-assisted. Shortly after, Carl Steinitz and his associates (Harvard Graduate School of Design) began to develop an automated "geographic information system" (GIS) to manipulate data geographically referenced to a position on the Earth's surface. Steinitz and his associates developed the first widely accepted geographic information systems software—IMGRID. Data elements used in IMGRID software are the data equivalent of the picture element of Landsat data (pixel):[*] attributes could be assigned to grid positions (X, Y coordinates) or cells, with each cell representing specific areas of the surface. Because both Landsat processing systems and IMGRID use computerized digital storage and manipulation techniques, it is possible to link the two systems by computer to perform rapid analysis.

In particular, it is possible to present to the user multiple solutions to a resource management question based on values specified by the user. GIS technology blossomed in the late 1970's; these GIS software packages were made available to the States at little or no cost.

Several small companies started up which used the same technology, but modified the software to suit particular markets—primarily energy development. A few private firms added Landsat data-processing software to their systems, but most relied on users to obtain their own Landsat data. The applicability of Landsat data to resource management is now clear: many States accepted the startup expense associated with processing Landsat data because they were to obtain final products that could assist in managing their limited resources.

Currently, about 19 States have developed geographic information systems (table B-1). Not all of these systems have direct Landsat data-processing capability, but most do utilize Landsat data in some form. These geographic information systems are, for the most part, less than 3 years old; they were developed in response to pressures for increased efficiency and the recognized need to develop an information network among State agencies. Texas and Minnesota have systems which have been in existence for more than 10 years.

State agencies have approached the development of State systems in two ways. The first, and less successful, scheme has been to spend millions of dollars on hardware, software, and staff. The aim was to establish a very large, technically sophisticated system to serve all users for digital data, satellite data proc-

Table B-1.—State Landsat Data Users With Geographic Information Systems

Alabama
Alaska
Arizona
Florida
Iowa
Kentucky
Louisiana
Maryland
Minnesota
Mississippi
Montana
Nebraska
New Jersey
North Carolina
New Mexico
Ohio
South Carolina
Texas
Virginia

SOURCE: This listing is not comprehensive and does not include reference to the several universities which support State systems.

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[1] Ian McHarg, *Design With Nature* (Garden City, N.Y.: Natural History Press, 1969).

[*] Each pixel covers an area on the ground of about 1.2 acres.

essing, resource management, and analysis. Because they are costly and unwieldly, these systems produced both users and strong opponents within State governments; about half have fallen into disuse and currently are not operational or are severely underutilized.

The second approach has been one of a very measured growth, with systems acquisition and staff development based totally on user demand for projects which could utilize Landsat and GIS technologies. The systems that have evolved from the second approach, while smaller and much less sophisticated, are the most stable and are beginning to grow larger as demand for them increases.

Landsat Data and the Decisionmaking Process in Mississippi

The Mississippi Automated Resource Information System (MARIS) was created by Executive Order 459, signed by Gov. William F. Winter in May 1983. Mississippi had joined with other States in developing a broadly based system for acquiring, storing, analyzing, and disseminating cultural and natural resource data.

Much earlier, in 1970, a group of 10 State agencies had met with NASA officials from the Earth Resources Laboratory located at Bay St. Louis, Miss., to obtain NASA's help in developing statewide land-use maps based on aerial photography. Participants at that meeting agreed that the State would provide interpretation of aerial photography, and that NASA would provide the aircraft from which the aerial photography would be obtained.

NASA supplied 1:120,000 color infrared photos which the Mississippi Research and Development Center enlarged to 1:24,000 and printed in black and white. U.S. Geological Survey quadrangle sheets were used as geographic reference control. These photos were manually interpreted by the R&D center and participating agencies' staff using the Anderson Classification System employing 51 categories of land use. The training and quality control were provided by the R&D center and a Lockheed consultant.

The project produced 1,440 manually interpreted photos (one per township). These became the statewide land-use base map. The mapping project, which was not completed until 1975, ultimately required a combined effort of the 10 sub-State planning and development districts, the University of Southern Mississippi, NASA, and the Mississippi Research and Development Center.

This photographic data base was completed during the peak of the U.S. Department of Housing and Urban Development's (HUD) 701 Planning Program, a program that required each of the State's 10 sub-State planning districts to produce future county land-use maps for their multi-county areas. To assist those districts in developing future land-use plans, HUD suggested that each sub-State planning and development district, using the State mapping project's aerial photography as a base, prepare overlays depicting selected factors that would affect future land-use development. The overlays included 100-year flood plains, prime agricultural lands, dilapidated housing, water and sewer districts, areas of ecological concern, and noise hazards.

The actual use of these hand-drawn overlays met with marginal success. At that same time, the traditional approaches to land-use planning were coming under heavy attack because of the top-down planning philosophy encouraged by the HUD programs. The HUD 701 program had failed to educate decisionmakers in dealing with problems associated with managing the growth they began to face in the late 1960's and early 1970's. When Federal funding of planning activities faded, it appeared that in Mississippi land-use planning would cease to exist. However, the problems associated with growth continued to mount, and the need for land-use planning or, as it began to be called, "resource management," became obvious even to the most skeptical. If State or local officials were going to make resource allocation decisions, they needed understandable and accurate information on which to base those decisions.

Major advances in the acquisition and manipulation of land-use related information were made during the early 1970's. Landsat 1 introduced a new and exciting data source. Computerized data management systems, geographic information systems, and Landsat satellite digital data all became readily available to planners and resource managers. The problem no longer was the acquisition and manipulation of data, but how to introduce the user to the land-use management process. The problem now was to generate a "defensible process" for regional planning or resource management.[2]

At this stage, recognizing the advances in data acquisition and management, many States invested hundreds of thousands and even millions of dollars in sophisticated computer equipment which gave them the capability to process these new digital data. Mississippi, however, did not have the capital available to purchase one of these sophisticated data management systems, and, therefore, had simply to observe the progress of other States. Many of these systems proved to be as much of a disaster as the old HUD 701 Land Use Planning Program. It appeared that the potential users would not accept and could not deal with sophisticated methods for managing data exhibited in these systems. A few systems failed and were closed down completely, and others were underutilized. The ingredient lacking in most States whose systems had fallen into misuse was a strong user community properly educated in the use and application of these new technologies.

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[2] Carl Steinitz, *Defensible Processes for Regional Landscape Design*, Harvard Graduate School of Design, Latis vol. 1, No. 1, Washington, D.C., 1979.

To develop a geographically referenced information system for Mississippi, the system had to be cheap, and it had to produce products that were immediately usable by State agencies in fulfilling their mandated responsibility. In the tradition of Mississippi government, the organization would have to be voluntary. Membership would be only those agencies which could be convinced that they directly benefited from membership. Because legislators of the State of Mississippi sit on the boards of all major State agencies, the legislators must be convinced directly that new systems are beneficial. Representative Wes McIngvale, of Batesville, Miss., was the original advocate of automated systems technologies and information-sharing networks in Mississippi. He wished to see the State central data-processing computer network heavily used by State agencies.

The first organizational meeting involved only directors representing the four agencies that would most obviously benefit from a new information network.* These agencies also had been exposed to satellite and geographic information systems through past projects. The Mississippi Department of Energy and Transportation agreed to provide staff support and to house any specialized hardware. This group, with assistance from the R&D center staff, prepared a "policy structure" for the system. The term "policy structure" was painstakingly selected to describe an organization which assisted in policy decisions, but did not make policy decisions. A primary mandate was that this organization would not become a new agency or level of bureaucracy. Its purpose would be to reduce the cost of agency operations and assist all members in their legislated functions. It would also serve to educate and inform member agencies about automation. Users of the system would have the ability to play "what if" games based on the iterative capabilities of the computer system and multiple data sources. Two new technologies were to be introduced by the Mississippi Automated Resource Information System (MARIS)—geographic information systems and Landsat satellite data.

Using these criteria, a consortium of 19 State agencies was formed. It is directed by a policy committee made up of the agency directors from each of the 19. The MARIS central staff oversees the operation of the specialized computer system which serves MARIS member agencies. This computer is a stand-alone system with software that allows for interpretation of multispectral scanning (MSS) and thematic mapper (TM) satellite data. The software also includes a geographic information system.

MSS and TM data provide a quick and reliable source of historic and current land cover data. When properly geographically referenced, these data can be compared with other data concerning topography, flood hazards, or census. This ability to combine data and compare and analyze their interactions is of great value.

Two major functional divisions make up the MARIS organizations: the MARIS catalog and the MARIS analytical effort. The MARIS catalog is an interactive computerized catalog of natural resource and cultural data. The catalog allows a user with the proper I.D. to query the State central data-processing records and ascertain the locations of reports and data stored in each member agency's files. The catalog can be searched by agency, publication title, or key word. Presently only a description of the document stored within each member agency files is available. However, more detailed information and actual data from the documents will be added next. MARIS can also be called on to aid in analyzing the data available.

User satisfaction is the key to the MARIS operation. MARIS is not funded directly in the State's budget. It depends on voluntary participation and support from its member agencies. If MARIS loses the support of its users, MARIS loses its funding. By supplying user agencies with data needs, MARIS has begun to build an impressive data base for Mississippi. The original aerial photography and overlays mentioned earlier have now been digitized and added to the State's geographic information system. New elements include the State's transportation network as classified by the Highway Department's standard classifications, major and minor watersheds as defined by the Soil Conservation Service, Federal and State park lands and preserved areas, water and sewer districts, 412 soil types, major population centers, and various interpretive maps based on these elements. Statewide models of preservation, conservation, and development suitability have been developed. Each model depicts the areas least suitable and most suitable for a specified use. The maps are not future land-use plans. They are presentations of levels of suitability for a particular use, and will serve as a policy tool for those agencies in State government that deal in development of the State's resources.

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*Mississippi Department of Natural Resources, Mississippi Department of Energy and Transportation, Mississippi Research and Development Center, and Mississippi Department of Economic Development.

The Mississippi Automated Resource Information System is unique among Southern States. It uses a state-of-the-art computer system and an active political system which provides support and guidance. The future of the system will depend on its ability to produce products usable to the consortium members. Cost, the aspect of MARIS most vulnerable to transfer of the Landsat system, is a major concern to member agencies. The MARIS central staff and the specialized computer system which they manage represent a major investment by the State of Mississippi.

Projects in Mississippi Using Landsat Data

Nuclear Waste Storage/Disposal Studies

A site in Perry County, Miss., has been selected as one of the prime sites for potential development of a nuclear waste storage/disposal site. The unique salt dome geology of the area possesses many attributes which appear desirable for such a facility. Mississippi has acquired Landsat data of the area surrounding the potential site and will classify these data to produce land cover maps of the area. Landsat data were found to be suitable in this study because the study area was predominantly rural in character, and high-quality Landsat data were readily available. The land cover maps will be merged with other elements stored in the State's geographic information system to assess the impact of the development of the facility and to assist in developing a management plan for the area. Other peripheral studies will include transportation access studies concentrating on nuclear waste transportation safety.

Delta Ground Water Studies

Although the Mississippi Delta has traditionally been the land of cotton, two new crops—rice and catfish—have made substantial gains in recent years. Rice area has increased to over 300,000 acres, and catfish farming is currently estimated to consume 60,000 acres of delta land. Because these new industries are heavy water users, ground water depletion is now a problem in the delta. The Mississippi Department of Natural Resources and several Federal agencies were asked to investigate ground water use and to assess future alternatives to manage the water resources of this most critical area.

With the assistance of NASA's Earth Resources Laboratory and a private consultant, Mississippi acquired and classified four 1981 scenes (two dates—July and September) of Landsat data of the Mississippi Delta. The product was a map of rice and catfish operations. These data were then merged into the State geographic information system. The spatial allocation of these operations affects ground water quantity available for irrigation. The allocation is also dependent on soil characteristics; clay soils make better field and pond bottoms than do more porous soils. The occurrence of existing rice and catfish operations can be expected to be consistent with the occurrence of clay soils and depletion of ground water.

An analysis is now being prepared which matches future rice and catfish operations to suitable soils in order to determine existing ground water availability. These data will be combined to produce spatial models of the area's agricultural and aquacultural potentials and their effects on ground water availability. Without Landsat satellite data, this study would have been more expensive* and could not have been based on multitemporal coverage of the entire delta region.

Statewide Land Cover Update

The State has acquired Landsat satellite data coverage for the entire State, which will be used to produce a statewide land cover element in the existing geographic information system. This will be the first statewide land cover classification since 1975, when aerial photography was used.

Land cover information acquired from the Landsat satellite has many advantages over traditionally acquired data when merged with a statewide geographic information system. They are consistent in format and resolution, are digital, and are therefore machine-processable; the same classification methodologies can be applied to all elements of the complete data set.

The level of detail acquired from Landsat data cannot match that of aerial photography. Therefore, the Landsat data will be grouped into approximately 12 to 15 classes instead of the 51 classes used in the photographic survey. However, the cost of the 1975 photo project was approximately $450,000. The cost of the Landsat project will be less than $75,000, which will be allocated over several projects. The 1983 cost of repeating the original photographic project would be over $1 million.

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*A cost comparison of Landsat data versus aerial photography was prepared as a first step in the data source selection. Although exact figures are no longer available, photography and the required manual photo interpretation would have added between $40,000 and $50,000 to this $42,000 project.

The Pacific Northwest Project: A Regional Resource Inventory Demonstration

In 1975, the Pacific Northwest Regional Commission, with support from NASA and the U.S. Geological Survey, initiated the Land Resources Inventory project for the application of Landsat data to resource problems on a regional basis. The project helped introduce new land-monitoring techniques and was a major Commission activity until its termination in 1980.

The primary objective of the Pacific Northwest project was to provide to a wide variety of natural resource planning and management agencies in Idaho, Oregon, and Washington, an opportunity to extract, apply, and evaluate information derived from Landsat multispectral data and other collateral sources. The results of the project were assessed by the users according to demonstrated utility and cost; these results formed an input to future monitoring and planning.

The use of Landsat data for public purposes is most effective when user needs in a given region are aggregated and the data can be applied to solving a variety of problems. The Pacific Northwest depends on its forests and irrigated crop lands as well as expanding urban areas around Puget Sound and inland; collectively, these present a range of informational mapping and monitoring needs. The project focused on the contribution to be made by satellite multispectral data modeled to the peculiarities of the region's vegetation, soils, and terrain.

The Pacific Northwest encompasses two major and contrasting ecoregions. Each is typified by a combination of climate, soils, and topography radically different from the other. They are sharply separated by the crest of the Cascades. The western or coastal portion of Washington and Oregon is classified as the Humid Temperate Domain. It contains the Pacific Forest and the Columbia Forest provinces. To the east and south lies the Dry Domain, an area of net water deficiency. This section is further subdivided into the Palouse Grassland, the Intermountain Sagebrush, and the Rocky Mountain Forest provinces.

The areas covered are extensive; for example, the Palouse Grassland covers 12,400 square miles and is an important wheat producer. The Willamette-Puget Forest covers 13,000 square miles and is a major supplier of forest products.

Under the aegis of the Pacific Northwest Commission, some 50 State agencies studied the economics of using Landsat data in a variety of applications. They undertook projects covering the major concerns over forest inventory, wildlife habitat, land cover, irrigated land inventory, urban areas, toxic weed occurrence, rangeland resources, reservoir volume, and surface mining.

A report prepared by the Commission lists examples of significant results attained on a State-by-State basis.

Idaho

- **Idaho Department of Water Resources.**—Surveys of 36 million acres of agricultural land were accomplished at a cost of $41,646, compared with a cost of $65,800 by conventional means.
- In a 4-million-acre area along the Snake River, yearly increases in irrigated land were recorded and crop types identified. A multistage statistical analysis incorporating Landsat data was developed and integrated into the activities of the Idaho Department of Natural Resources.

Oregon

- **Oregon Fish and Wildlife** reported a cost savings of 43 percent using Landsat for habitat inventory.
- **Oregon Water Resources Department.**—By interstate compact, the extent of irrigated farmland along the Klamath River Basin is reported. The department developed a system depending in part on Landsat data for monitoring irrigation.
- **Oregon Department of Agriculture.**—Landsat digital data were used to identify areas of a noxious weed, the Tansey Ragwort. Infestations of the weed cause $3 million to $8 million a year in direct losses of livestock.
- **The Department of Transportation,** along with other agencies, used Landsat data to determine the type and percentage of land cover. They produced statistical summaries as an aid to zoning and pollution control. The department adopted the method for continuing use.

Washington

- **Washington Department of Natural Resources.**—An estimated cost saving of 48 percent was achieved in a forest inventory covering over 13 million acres.
- A timber volume inventory was conducted in western Washington involving analysis of data from 20 million acres. The resulting information was used in State productivity studies and the technique was adopted and expanded by the Washington Department of Natural Resources.
- **Central Puget Sound,** a multiagency organization, incorporated Landsat data into urban planning in an 8,000-square-mile area. It used the results in transportation planning and water and air quality

studies. A new computerized data base was prepared and put into use by the city of Tacoma.

Governor Straub of Oregon, State cochairman of the three-state project, concluded in a letter to the Administrator of NASA that Landsat has provided a new, more effective and less costly source of management data. He emphasized that the involvement of a "critical mass" of individual agency participants is prerequisite to proving the overall value of Landsat data on a State regional basis. He further stated that "the acquisition of equipment and changeover to a new data base can be an expensive proposition" and that "the most critical element is continuity of data. Without assurance of continuity, States cannot accept the risks of utilizing Landsat data as a primary tool."[3]

In a letter to the Chairman, Office of Science and Technology Policy (OSTP) of the White House, the chairman of the Pacific Northwest project's Technology Transfer Task Force commented on remote-sensing capabilities demonstrated in the Pacific Northwest. He said that much of the information derived is being used for remote areas where data were previously unavailable. The letter noted the uniqueness of the Landsat system to provide frequent coverage which " . . . establishes a historical record of the changes and transitions." He pointed out that from fiscal year 1975 through fiscal year 1979, roughly $6.5 million was committed by participating agencies—Federal, State, and local. As a result of the success of the initial 3-year demonstration, a follow-on Landsat applications program was approved which provided for a larger share of funding by local participants. The States began the purchase of software as well as arranging access to major hardware systems for the exploitation of the data on a continuing basis.

Following several years of experience with remote-sensing systems, the Commission stated, "It is our strong belief that the Federal Government should continue to be responsible for Landsat research and development as well as Landsat data at the Federal level. The burden of analysis belongs at the State and local level with the agencies and communities that will apply the data in their planning and management decision-making process."[4]

In the course of about 5 years, project leaders made a number of management decisions. Partly in view of the unknown or unresolved future of the Landsat series, the States determined that rather than set up a single regional data center, each would be responsible for its own data handling and processing schemes. Considerable Landsat data are now stored in various computer banks in the region. However, the abolition of the Commission in 1980 removed a key coordinating body. Although many of the original participants continue to exchange data and to interact with one another through professional meetings and on a collegial basis, an essential part of the cooperative program now is absent. Nevertheless, as a direct result of the demonstration project, the States involved have acquired the improved capability to perform digital analysis and manipulation of Landsat and other georeferenced data on State computers. This operational capability, to greater or lesser degree, continues to be employed as funds and availability of data permit.

Effects of Private Ownership on Use of Landsat Data

At a conference on natural resource inventory methods held in Corvallis, Oreg., in August 1983, three of the leading participants in the Pacific Northwest project were asked to react to the proposed transfer of Landsat to private ownership. They expressed the following concerns:

- **Cost.**—The profit incentive may raise costs to levels unacceptable to State managers.
- **Data Continuity.**—If the Landsat program should not prove sufficiently profitable, it might become only seasonally active or be abandoned altogether.
- **Uncertainty.**—The private sector is not accountable to the users in the sense that public agencies are; therefore, there could be a relaxation of quality control and service.
- **Monopoly.**—Private sector monopoly could mean less incentive to improve service and keep costs down.
- **Prioritization.**—Data availability may become restricted and preference shown to those parties who can afford to pay the highest prices to receive data or to reserve time of limited transmission and/or processing capabilities.
- **Data Archive.**—A private sector operator may choose only to collect, process, and store those data that have been requested and paid for. Therefore, data of less productive, remote areas may go uncovered and historic data for many regions may become unavailable or nonretrievable.
- **Support Photography.**—The private sector operator would not be motivated to provide ancillary support to Landsat projects by such things as U-2 underflights and ground checking.
- **Data Processing.**—The private sector might not choose to put in the time and dollars necessary for cleaning up and processing the data as is cur-

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[3] Letter from Governor Straub of Oregon, State cochairman of the three-State project, to NASA Administration, 1979.

[4] Letter from Wallace E. Hedrick to OSTP, May 5, 1978.

rently done. Alternatively, the operator might not do it as well or might charge extra.

- **Data Inquiry.**—The present free search and inquiry service, considered a public service, might become unavailable or available only at a price.
- **Data Restriction.**—The distribution of data may no longer be on a nondiscriminatory basis, but instead may either be made available to the first party to order or subjected to a price bidding where the party that can pay the most will reserve data and processing time.
- **Landsat Data Users Notes.**—The Government publication describing Landsat activities may stop.
- **Research.**—Many research and application demonstration projects now occurring at government and other public facilities may stop or else only continue with a charge for the findings. Research might not be conducted with complete objectivity if the end is to support market development.
- **Technology Feedback.**—Linkages with university and other research facilities are beneficial for learning new technological approaches and require free give-and-take and feedback. Such an arrangement might not be possible for a private operator.

Appendix C

Survey of University Programs in Remote Sensing Funded Under Grants From the NASA University-Space Application Program[1]

Summary Conclusions

- All of the programs surveyed have attained some level of State/local involvement. One program has worked in projects with 39 State agencies, maintains regular contact with 74 others, and has 150 other contacts that can be drawn upon as needed. Such involvement depends on seed money to demonstrate applications before State/local agencies will provide funding.
- NASA grant funding has reduced the time which would otherwise be expected for State/local governments to become operational users of remote sensing. NASA grants are the base which assists and supports university programs to demonstrate proven applications to first-time users. The States will generally not support development/demonstration programs.
- State governments are beginning to use remote-sensing technology and capabilities in operational areas. Capabilities have, in general, not been institutionalized in the sense that many programs would not continue if NASA seed support were withdrawn.
- About 9 percent of the total funding in 1977 was from State and local sources. Estimates for prior years indicate that State funding is accelerating as remote-sensing applications are beginning to be applied in State and local programs. In many programs, significant nonfinancial support is contributed by the university (faculty and graduate research assistants), and by State/local agencies working with the university.
- Total funding for the university programs surveyed has grown approximately 50 percent since 1974. A large part of non-NASA funding comes from Federal sources to develop applications which also interest State, local, and private users. NASA grant funds have been an important stimulus to attracting non-NASA Federal funds.
- The programs are adaptive to the expressed interests of State/local governments. The distribution of application areas and specific expertise developed reflects State/local interests and funding patterns. State/local participation is dependent on the applicability of remote sensing to near-term problems.
- University participation in remote-sensing is large and growing. Some universities offer several courses in specific remote-sensing disciplines. Overall, during 1977, 137 courses were taught to a total of 2,906 students; 195 faculty members and 393 research assistants were involved in the research projects.
- Sixty-five percent of the programs have minor private sector involvement, which ranges from geoexploration assistance for the major oil companies to rangeland productivity projects with local ranchers.
- Twenty-five percent of the programs have foreign involvement. The University of Utah, for example, has a $150,000 land-use project with the Government of Korea.

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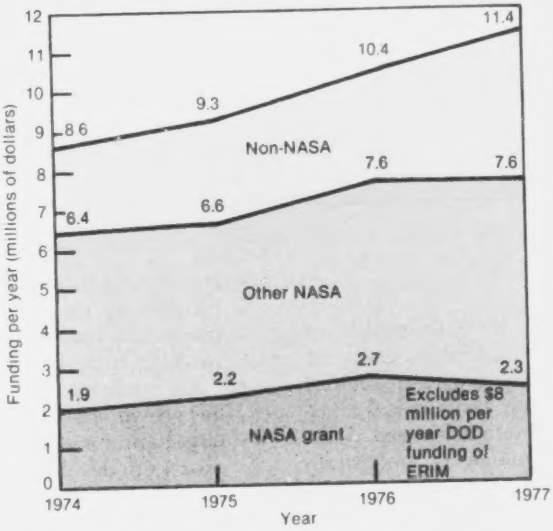
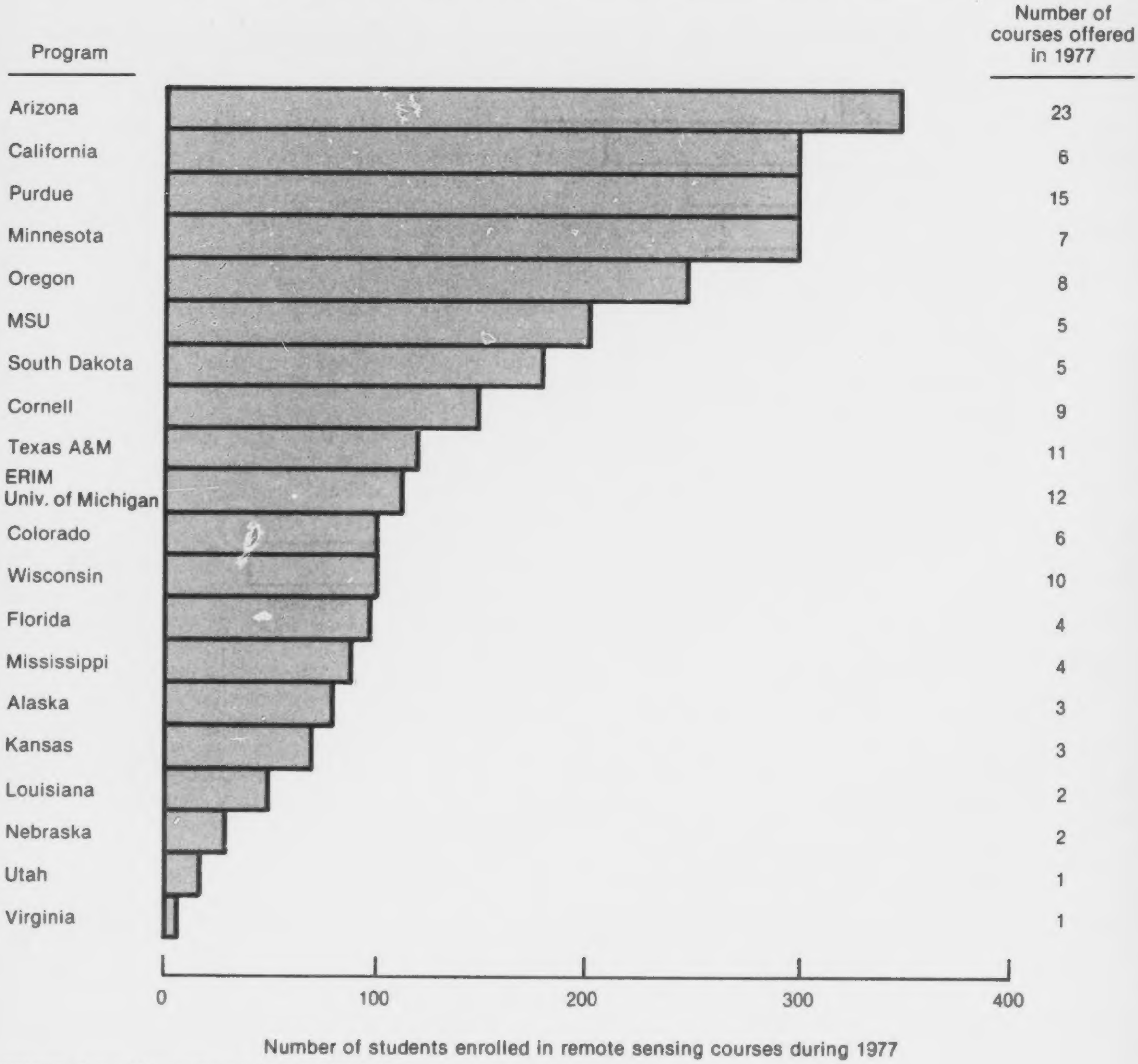
[1] J. A. Madigan and R. W. Earhart, NASA contract No. NASw-2800, task No. 27, Battelle Columbus Laboratories, report No. BCL-OA-TFR-78-3, Mar. 31, 1978.

Figure C-1.—University Programs: Sources of Funding 1974-77



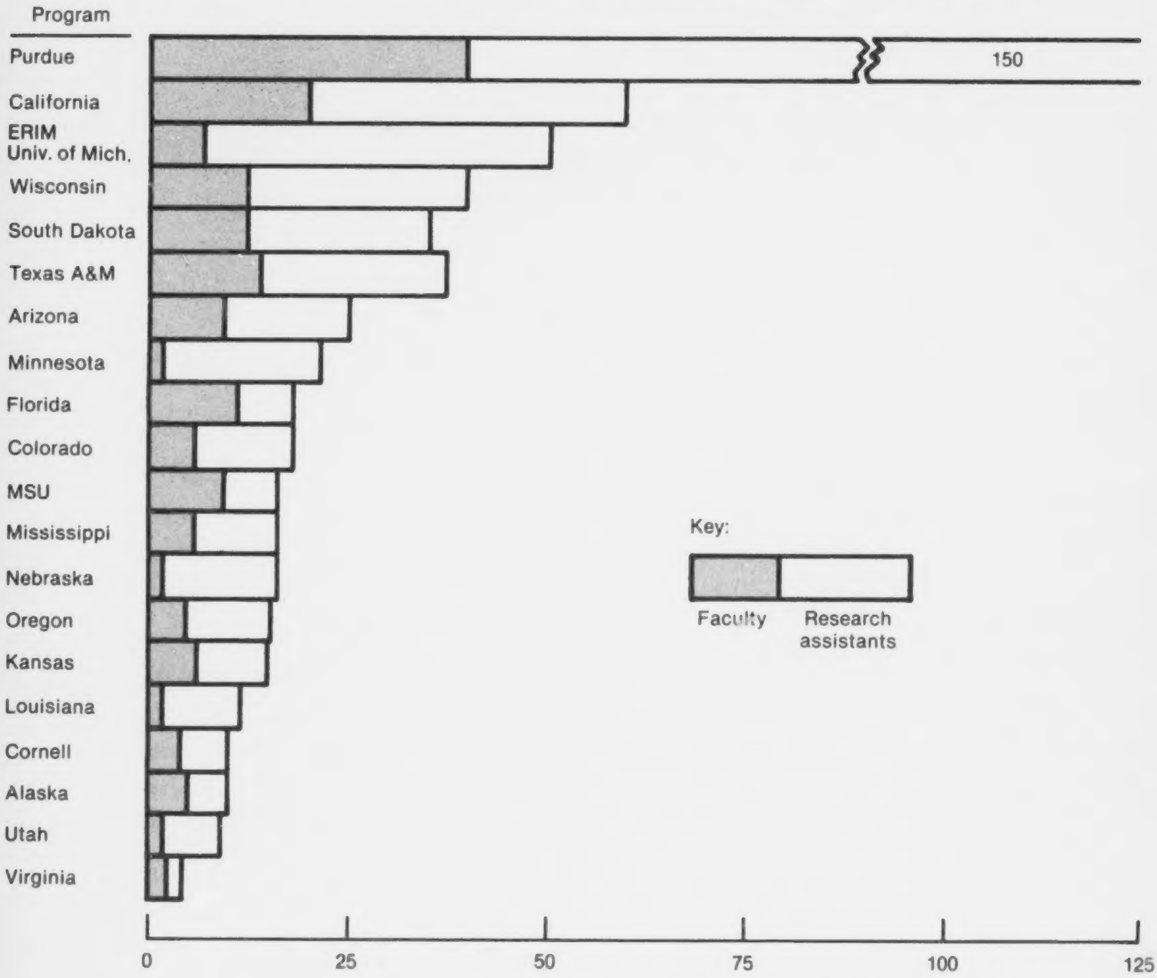
SOURCE: National Aeronautics and Space Administration.

Figure C-2.—Students and Courses in University Remote Sensing Programs



SOURCE: National Aeronautics and Space Administration.

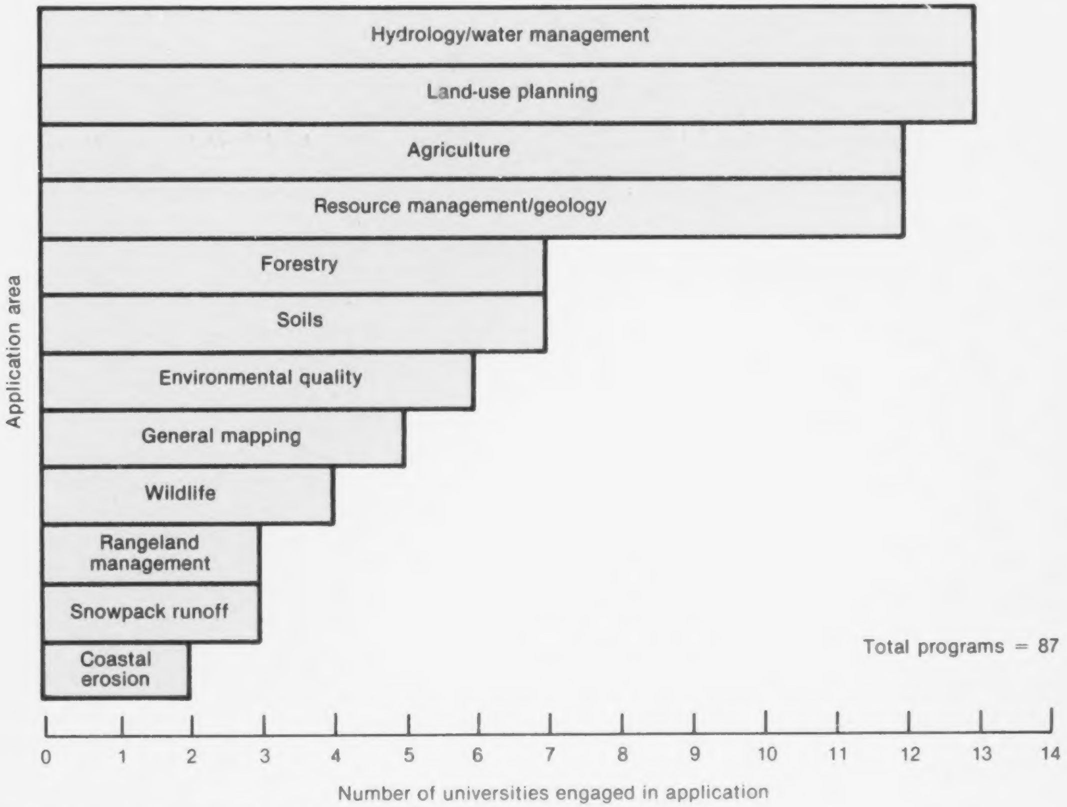
Figure C-3.—Faculty and Research Assistants in University Remote Sensing Programs



Number of faculty and research assistants participating in programs during 1977

SOURCE: National Aeronautics and Space Administration.

Figure C-4.—University Programs: Major Applications of Remote Sensing



SOURCE: National Aeronautics and Space Administration.

Appendix D

Remote Sensing in Agriculture

In the late 1960's, work began on aircraft and space remote multispectral sensing systems for agricultural applications. The Laboratory for Application of Remote Sensing (LARS) at Purdue University did much of this initial work and showed how to use data from multispectral sensors to classify major agricultural crops.[1]

The corn blight watch experiment[2] in 1971 demonstrated that a single crop—i.e., corn—could be identified by multispectral techniques and that variations in crop health—e.g., blight infection—could be mapped with multispectral data. The corn blight program showed the validity of the concept using aircraft, but it took experiments on Apollo 9 to demonstrate[3] that crops could be recognized and mapped from space.

Early experiments conducted with Landsat over a series of test sites—e.g., the joint U.S. Department of Agriculture (USDA)/Canada spring wheat program[4]—showed clearly that Landsat data could provide useful information, though their ability to separate similar crops like spring barley and wheat was limited.

The National Aeronautics and Space Administration's (NASA) LACIE (Large Area Crop Inventory Experiment)[5] was designed to extend the early wheat test results to other wheat areas of the world. While success was claimed for the LACIE program, it is clear that major questions remained about the ability of Landsat data to discriminate between crops and about the negative effects of extensive cloud cover. These problems: 1) reduced the effectiveness of the system to assess crop area, a major objective of LACIE; and 2) severely limited the ability to use satellite data during the growing season.

The results of the U.S./Canadian spring wheat experiment led to two conclusions, that: 1) Landsat data are at their best when used to assess the stress conditions of the agricultural system, and 2) a system was needed to allow daily computer simulation of the agricultural scene using basic modeling of soils, precipitation, solar radiations, and plants.

These conclusions implied that it was possible to develop a cost-effective crop assessment system. Such a system should reduce concentration on crop area mapping during the year in question from Landsat, and emphasize instead crop yield relationships inherent in the crop stress information available from the Landsat spectral data. A crop simulation system (conclusion 2) would provide the framework in which to use the Landsat crop stress information as well as provide useful crop assessments when clouds obscured the field of view.

Development of the crop simulation system, initiated in 1973,[6] concentrated on the use of the meteorological satellite data to overcome the limitations of ground meteorological reporting stations. This approach had the distinct advantage of offering the potential of a near continuum of the meteorological data needed to run plant simulation models. The system was first tested in Iran;[7] later tests were made in the United States under the NASA LACIE programs. The results showed the metsat-based simulation system to be sound, but in need of further development.

In 1976, another test of the system was run to test the ability of the system to assimilate Landsat crop condition information and thereby improve yield estimates; it showed that Landsat crop condition data did improve when yield estimates made by meteorologically derived yield simulation models were added.

In 1977, Earth Satellite Corp., a value-added company, placed the Landsat/metsat conjoint simulation system in commercial operation over various areas of the world. This value-added system, called CROPCAST™ now covers over 12 different crops in 12 countries.

Landsat Data Uses

Landsat data today offer opportunities to provide the following useful data to agricultural assessments:

- spatial distribution of potential crop yield classes in three to six unique categories;
- spatial location of winter kill in winter wheat areas of the world;
- area of irrigation in a crop area;

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[1] "Remote Multispectral Sensing in Agriculture," Bulletin 844, Laboratory for Application of Remote Sensing (LARS), Purdue University, vol. 3, Annual Report, September 1968.

[2] "Corn Blight Watch Experiment Final Report, Experimental Results," NASA SP-353, 1974.

[3] "Crop Surveys From Multiband Satellite Photography Using Digital Techniques," LARS Information Note 032371, Purdue University, 1971.

[4] "An Investigation of the Feasibility of Developing a Semi-Automated System for Monitoring Spring Wheat Production," prepared for the USDA (ASCS), contract No. 123341024, May 1974, by Earth Satellite Corp., Washington, D.C.

[5] "The Large Area Crop Inventory Experiment (LACIE)," in Proceedings of the NASA Earth Resource Survey TM X-58168 JSC 09930, June 1975, Houston, Tex.

[6] "Iran Agriculture Program: Evaluation of Techniques and Procedures," prepared for the Ministry of Agriculture Iran, Interim Report June-October 1974, Earth Satellite Corp., Washington, D.C.

[7] "CROPCAST Crop Reports," vol. 5, issue 15, Aug. 15, 1982, continuing series of CROP Reports, prepared by Earth Satellite Corp.

- areas of abandonment—i.e., planted fields that are not harvested because of low yield or other reasons;
- replanting areas—i.e., areas where another crop is sown in the spring following losses to a winter crop;
- soil moisture distributions at planting times;
- snow cover and perhaps depth assessments;
- winter wheat crop area at spring green-up; and
- flood area mapping and crop damage assessment.

USDA started using some of these Landsat-derived data on a routine basis in 1980. CROPCAST™ introduced some of the Landsat data in 1977 and expanded their use in 1983, after negotiating a program with the Swedish Space Corp. in Stockholm to provide near-real-time Landsat analyses directly from the Swedish Landsat station at Kiruna. The Swedish analyses provide Landsat data to CROPCAST™ in 4 to 5 days after acquisition. This compares favorably with the scales of 4 to 5 weeks for the USDA Foreign Agriculture Service operation in Houston.

In addition to the highly dynamic, real-time applications discussed above, Landsat data are used in various other ways to assist with agricultural problems:

- soil maps are prepared over areas that have limited conventional soils data,
- Landsat data are used in the design of a crop area sample survey design, and
- irrigation potential can be mapped using Landsat data.

Specific Examples of Key Landsat Information Applications

Operational use of Landsat data in agriculture centers primarily on the delineation of stress and irrigation potential. Some recent examples drawn from CROPCAST™ operations include:

- The 1983 delineation of drought stress in the Odessa region of the U.S.S.R. The meteorological models indicated dry conditions and stressed plants, but Landsat provided positive evidence that this was true.
- The 1983 confirmation of drought stress in Rumania and other Eastern Europe areas.
- The 1980 delineation of the drought stress in soybean areas on the west side of the Mississippi in Arkansas. The meteorological system had indicated general problems, but Landsat data provided a detailed inventory of the stressed fields.
- In 1981, China was undergoing drought in the Bejing area. The meteorological models and ground reports of drought conflicted because of the extensive use of irrigation in the area. Landsat data ordered from the Japanese ground station provided verification of a serious decline in the irrigation reservoirs and the existence of some crop stress.

These few examples show the value of Landsat data to confirm, and thus to add confidence to, agricultural assessment worldwide.

Meteorological Satellite Data Uses

Meteorological satellite data from both geosynchronous and polar orbiters are used routinely in the CROPCAST™ Agricultural Simulation System. The AgRISTARS program also includes plans to use them on a routine basis because they provide a quantitative source of precipitation estimates for many value-added meteorological services in the United States and overseas.

In the current CROPCAST™ system and in the planned AgRISTAR in 1986, the data from the geosynchronous meteorological satellite from the United States, the European Space Agency, and the Japanese provide a primary input to a global analysis of rainfall and solar radiation—key factors in plant simulation models.

The manipulation and analysis of metsat data by Earth Satellite Corp. provides a useful example of how value is added to primary satellite data. Data from the U.S., Japanese, and European metsats are delivered to Earth Satellite's offices via the National Oceanic and Atmospheric Administration (NOAA) and NASA facilities. Earth Satellite takes facsimile photographs received over this system, converts them to digital form and enters them into a common grid system with various other kinds of data. After processing by computer models, analyses of soil moisture, plant growth, stress, yield, etc., are produced. The spatial resolution of these analyses, obtained with the use of the satellite data, is unobtainable in any other way.

Data from the polar-orbiting NOAA satellites* are used in the CROPCAST™ (and will be used in future AgRISTARS programs) in two ways; one is to supplement the geosynchronous data at latitudes above about 50° N and S, the other is to make use of the resolution (1 km) and spectral capabilities of the polar orbiters to map vegetation, flooded lands, and snow cover.

The ability to map vegetation is made possible by sensors operating at wavelengths of 500 to 700 nanometers and 800 to 1,200 nanometers. These spectral bands measure the level of plant reflectance in the red and infrared parts of the spectrum in the same way that the Landsat multispectral data are used. The 1-km resolution will only resolve large fields, but the spectral capability provides excellent delineations of vegetation stress over large areas.

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*From the automatic very-high-resolution radiometer (AVHRR).

The low-resolution, low-cost data from the polar orbiters have many advantages in comparision with higher resolution Landsat data; among them are daily coverage and broad area vegetation condition mapping. These attributes make the data very attractive to customers of value-added services, to the future USDA AgRISTARS program, and to the U.N. Locust Program. The following examples illustrate some actual uses of these data by CROPCAST™ since 1980.

- The U.S.S.R. coverage by Landsat is limited to the western half. In 1982, polar-orbiter data were used to map crop stress in the U.S.S.R. spring wheat belt, and thereby accurately to assess yield.
- In 1973, drought and fires dotted the cacoa areas of west Africa. CROPCAST™ used these data to delineate the drought area and to estimate the location and extent of the damaging fires.
- In 1980, polar-orbiter vegetation analyses were used to map the extent of the drought in the United States.
- In 1981, 1982, and 1983, polar-orbiter vegetation analyses were used to assist in assessing sugar beet yields in the European Community and the U.S.S.R.

In the foregoing examples, the use of only polar-orbiter data was discussed; however, conjoining data from the metsat and Landsat systems leads to cost-effective ways to use these data in agricultural assessments.

Conjoint Applications of Landsat and AVHRR Meteorological Satellite Data

Landsat data by themselves have some significant limitations—e.g., the satellite views the same point on the ground at intervals of only 16 days, thereby reducing the data's potential to monitor short-term changes in crop condition and other factors. On the other hand, Landsat data offer higher resolution. Although polar-orbiter data possess lower resolution (1 km at best) the satellite views the same area once per day, in daylight, and once per night.

Conjoining data from both the Landsat system and AVHRR offers improved confidence in delineating vegetation stress because Landsat data provide calibration samples on which to "tune" the AVHRR data. Tests conducted by Earth Satellite Corp. indicate that AVHRR data used in this way over the U.S.S.R. can provide accurate crop stress information at a cost significantly less than that obtained from Landsat alone. The data are also available more reliably because the daily passes allow cloud screening not possible with Landsat.

NOAA polar-orbiter data will be used more and more in agriculture as users learn how to acquire and process the data. Data from Landsat, SPOT, or other higher resolution satellite systems will continue to be important for calibrating these data.

Appendix E
Hydrology

Meteorological Satellite Data

The river and flood forecasting service of the National Weather Service (NWS) produces more than 400,000 forecasts annually for about 2,500 riverside communities from its 13 River Forecast Centers.[1] The NWS, the U.S. Army Corps of Engineers, and the U.S. Geological Survey operate thousands of river gages that transmit data via the geostationary meteorological satellite (GOES) to central sites for near-real-time analysis. Transmission via satellite solves the common problem of interrupted service during floods. All these agencies, as well as local and regional water authorities, are continually expanding their use of satellite transmission of data.

For the past 10 years the metsats have been used for mapping the areal extent of snow in river basins in the Pacific Northwest and California to improve river forecasts on the Columbia River and the rivers draining the Sierra Nevada. Rainfall estimates from convective storms and hurricanes are now routinely done by the National Environmental Satellite Data Information Service (NESDIS) at the National Oceanic and Atmospheric Administration (NOAA). They draw heavily on the satellite measurement of cloud-top temperatures and the rate of growth of cumulonimbus clouds from the half-hourly images taken by the GOES satellite.

Another important unknown in the hydrologic cycle is soil moisture, which controls the amount of precipitation that will form storm runoff. Some thermal infrared experiments indicate that this technique has promise, but no operational soil moisture estimations are currently being made.

Flood mapping from both NOAA polar-orbiting and geostationary satellite imagery and data has been demonstrated under cloud-free conditions on large rivers such as the Mississippi, and on smaller rivers with wide flood plains such as the Red River of the North (North Dakota and Minnesota) and the Kentucky River. The daily coverage of the metsats provides opportunities to map the progress of the flood as it moves across a large basin drainage system. The thermal infrared channels permit nighttime flood mapping.

Several new hydrologic models for basins that have substantial snowmelt contributions have been developed to use the new snow-area data made available by satellites.

The AgRISTARS program of the Department of Agriculture includes a large amount of hydrologic data derived from NOAA satellites. Hydrologic requirements are integrated into almost all sub areas of the program:

- early warning and crop condition assessment,
- commodity production forecasts,
- renewable resources inventory and assessment,
- land-use classification and measurement,
- land-productivity estimates,
- conservation practices assessment, and
- pollution detection and impact evaluation.

Some of the hydrologic information developed from metsat data under the AgRISTARS program involved: flood damage assessment, warning of the onset of drought, soil-moisture modeling, rainfall, solar radiation, vegetation indices, land-use changes, and snowpack characteristics.

NOAA has used satellite data to provide evaporation estimates for Lake Ontario, to detect ice dams on rivers and ice conditions on the Great Lakes, and to determine the best ship routes on the Great Lakes.

NESDIS routinely prepares thermal maps of the Great Lakes. In addition it is able to detect coastal circulation patterns at river mouths, estuaries, lakes, and bays using the thermal infrared channels.

In sparsely settled Canada, the use of metsat data has been widespread. Snow cover mapping, freezeup, and ice breakup on large lakes, flooding, and telemetry of hydrologic data are common applications; because of the vastness and remoteness of much of the Northwest Territory, use of the data is increasing in popularity. The Atmospheric Environment Service, the Canadian Centre for Remote Sensing, and the various Provinces are heavily involved in these hydrologic applications.

Metsat data (channels 1 and 2) are also used to produce vegetation indices. The Goddard Space Flight Center of the National Aeronautics and Space Administration (NASA) has prepared a series of computer-enhanced images of Africa showing by color the vegetation of the country. NOAA/NESDIS now produce vegetation index maps of both the Northern and Southern Hemispheres on a weekly basis (see figures in app. H).

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[1] R. A. Clark, "Satellite Applications in River and Flood Forecasting," in *Satellite Hydrology*, M. Deutsch, D. R. Wiesnet, and A. Rango (eds.), Proceedings of the 5th Annual W. T. Pecora Memorial Symposium on Remote Sensing, 1979, Sioux Falls, S. Dak., 1981, pp. 6-8.

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In Bolivia, GOES data have been used to determine convective storm characteristics in small- or medium-sized basins for the design of dams or other water-resource engineering development. Cloud indexing techniques have improved rainfall estimates in northwest Africa in connection with a desert locust control survey sponsored by the U.N. Food and Agricultural Organization.[2]

Snowpack can be routinely mapped with the 1-km resolution Advanced High Resolution Radiometer. Tests in California have shown that these measurements are equivalent in accuracy to traditional aircraft survey techniques.[3] Snow inventory and runoff forecasting in Norway have been done largely through NOAA polar-orbiting satellite imagery, with effective cost savings resulting from improved water-power management.[4]

Although the U.S. Agency for International Development (AID) has been the lead Federal agency in transferring the technology of remote-sensing to developing countries, it has commonly emphasized Landsat data rather than metsat data. NOAA has run training sessions for a wide variety of scientists and engineers at its U.S. facilities to assist in remote-sensing technology transfer as it pertains to the metsats. Much of this work has been financed by international and AID programs. NASA and the U.S. Geological Survey have also engaged in international on-the-job training for foreign nationals.

Landsat Data

Landsat investigations over the decade have proven the ability of the Landsat system to map floods, snow cover, and ice cover; delineate surface permeability; etc. Used together with meteorological satellite data, they offer a formidable resource survey tool:

- In 1973, some of the most disastrous flooding on the Mississippi River in recent years was mapped with Landsat, vividly delineating the extent of inundation over large parts of a major river basin.[5]
- Snow pack extent was mapped in California using Landsat data, resulting in reduced errors in stream flow forecasts.[6]
- Landsat data have been effectively used in South Dakota to model soil erosion. Landsat's unique contribution was in delineating land cover in the basin.[7]
- Landsat data have been used to enforce water pollution regulations. In this case they provided the extent of pollution and turbidity levels at a plume in Lake Champlain; these data were used in a court case against a New York papermill.

These examples are only a small sample of the total applications of Landsat data to hydrology. The limitations of the Landsat system in its applications to hydrology are similar to those in agriculture: timely coverage may not be available because of the 16-day repeat cycle. Part of this limitation can be overcome by using meteorological satellite data.

Conjoint Applications of Landsat and NOAA Polar-Orbiting Data

Used together, Landsat and NOAA polar-orbiter data offer a formidable resource survey tool. As in applications to agriculture, the role of Landsat data is to calibrate the more frequently gathered but poorer resolution meteorological satellite data. Some specific examples include:

- Use of Landsat data to calibrate the snow/no snow boundary. Once a reflectance value has been calibrated defining the reflectance of the snow boundary, then the NOAA polar-orbiter data can be used with high accuracy to map the snow boundary at less cost with greater frequency.
- The same rationale outlined for snow mapping works for flooding—i.e., Landsat spectral data—can be used to define a signature for flood-damaged vegetation and actual water areas where vegetation may be seen through the water. Once calibrated with the Landsat data, polar-orbiter spectral data can be applied to map the flood boundaries.
- Land cover and deforestation which may influence a watershed runoff can be mapped using the

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[2] E. C. Barrett, "Satellite Rainfall Estimation by Cloud Indexing Methods for Desert Locust Survey and Control," in *Satellite Hydrology*, M. Deutsch, D. R. Wiesnet, and A. Rango (eds.), Proceedings of the 5th Annual W. T. Pecora Memorial Symposium on Remote Sensing, 1979, Sioux Falls, S. Dak., 1981, pp. 92-100.

[3] D. Wiesnet and D. McGinnis, "Hydrological Application of the NOAA-2 Very High Resolution Radiometer," in *Remote Sensing and Water Management, Proceeding No. 17*, American Water Resources Association, June 1973.

[4] G. Ostrem, T. Andersen, and H. Odegaard, "Operational Use of Satellite Data for Snow Inventory and Runoff Forecast," in *Satellite Hydrology*, M. Deutsch, D. R. Wiesnet, and A. Rango (eds.), Proceedings of the 5th Annual W. T. Pecora Memorial Symposium on Remote Sensing, 1979, Sioux Falls, S. Dak., 1981, pp. 230-234.

[5] M. Deutsch, F. H. Ruggles, P. Guss, and E. Yost, "Mapping of the 1973 Mississippi River Floods From the Earth Resources Technology Satellite (ERTS)," in *Remote Sensing and Water Management, Proceeding No. 17*, American Water Resources Association, June 1973.

[6] A. Rango and P. O'Neill, "Effective Watershed Management Using Remote Sensing Technology," in *Remote Sensing for Resource Management*, Soil Conservation Society of America, Ankeny, Iowa, 1982.

[7] B. J. Ripple and S. Miller, "Remote Sensing and Computer Modeling for Water Quality Planning in South Dakota," in *Remote Sensing for Resource Management*, Soil Conservation Society of America, Ankeny, Iowa, 1982.

Landsat system, but a calibrated NOAA polar-orbiter data set can be used at less cost.

Clearly the polar-orbiting metsat-Landsat mix offers many advantages that are yet to be applied. Improved delivery of data sets from the NOAA polar-orbiting metsat and Landsat systems would open the way for significant increases in the use of such mixes.

Appendix F

Forestry

Remote-sensing techniques have been widely used by forestry companies and individual consultants for many years. The most frequently used type of remotely sensed data are black-and-white panchromatic aerial photos, usually having a scale of 1:15,840 (i.e., 4 inches = 1 mile). Such photos show a tremendous amount of detail about the forest and other surface features; stereo pairs of photos can be used to obtain information about the species of trees present, number of trees per acre, areal extent of the forest stands, location and characteristics of existing or needed transportation networks, etc. Although a tremendous amount of highly useful information can be obtained from aerial photos, much of this information requires imagery having high levels of spatial detail—individual tree crowns, topographic characteristics of the terrain, etc. It is largely for this reason that many people have questioned the value of Landsat data for meeting information needs in forestry, since the ground resolution of each Landsat pixel is approximately 59 × 79 meters.

However, several different levels of detail are needed in characterizing or evaluating the forest resource. At the most detailed level, one must obtain actual measurements in the field from a sample of individual trees to estimate the merchantable timber volume per acre in individual stands of timber. On the other end of the scale, knowledge of the location and extent of forest stands is also important. It is this type of information for which Landsat data are of particular value, since the location and extent of forests can change dramatically over the course of a few years or even from one year to the next.

In other words, the average rate of growth of individual species of trees is known. Once the species composition of a specific stand has been determined, the changes in stand volume can be predicted reasonably well, barring unforeseen changes due to fire, insects, or disease. These unforeseen changes, from natural or human causes, require periodic assessment of the areal extent of forest lands; this can best be accomplished quickly and cost effectively by remote sensing. Traditionally, the forest industry has used aerial photography.

In recent years, as the quality of both aerial cameras and film has improved, and as the capability for obtaining photos from high-altitude aircraft has been developed, the use of relatively small-scale (e.g., 1:120,000) aerial photos has been of interest to forest industries because of the relative economy of such photography for many applications.

For example, in Maine, the Great Northern Timber Co. uses 1:120,000-scale color infrared photos for a wide variety of timber land and road network assessments, and for monitoring logging operations (i.e., the extent and location of clearcut areas). The company converts the information derived from these aerial photos into digital form and adds it to a data base which is part of a highly sophisticated Georeferenced Information System (GIS). The foresters at Great Northern are highly interested in the potential of Landsat data to supply much of the information they need, but they have yet not incorporated them into their procedures because of their concern about the continued availability of Landsat data in a standardized format, and the recent very large increases in the cost of the computer-compatible types (CCTs). If the price for digital Landsat data rises too high, they will continue to rely on aerial photography, where the cost of obtaining the necessary data and the source of data are known, predictable factors.

The Southern Timberlands Division of St. Regis Paper Co. (headquartered in Jacksonville, Fla.) has also developed a sophisticated GIS, which is tied into the corporate computer network. St. Regis foresters were interested in integrating the data from such a system into their forest management operations. Because some of the early research results appeared promising, St. Regis submitted a proposal to the National Aeronautics and Space Administration to evaluate the use of such data for meeting some of the information needs of the forest industry. St. Regis asked Purdue University to work with them on this project.

Researchers set up a three-phase evaluation of the Landsat data and digital-processing techniques. Phase I involved a detailed assessment of the benefits and limitations of using Landsat data to meet operational information needs of the Southern Timberlands Division. Specifically, the division wished to know the accuracy and reliability of identifying coniferous forest cover, the optimal times of year to obtain Landsat data, and the accuracy and reliability of acreage estimates. In addition, it had many questions concerning the procedures for incorporating such data into the existing resource management system, the cost and availability of hardware and software for utilizing Landsat data, personnel and training requirements, etc. They also wished to know the cost and timeliness as well as the continued availability of the Landsat data.

When dealing with a new technology such as this, a myriad of unknowns, both technical and financial, must be examined before it becomes reasonably clear that the technology can meet operational needs for specific types of information. The results of Phase I indicated that Landsat data and computer analysis techniques could provide useful input to a Forest Resource Information System (FRIS)—a computer-based GIS; approval was given to proceed with Phase II and III.

In Phase II, a computer terminal in Jacksonville was connected to the main computer at the Laboratory for Applications of Remote Sensing (LARS), Purdue University, where appropriate data analysis software existed. The staff at LARS trained St. Regis personnel in analyzing Landsat data. After St. Regis obtained additional equipment to implement completely the St. Regis FRIS, the "umbilical cord" to Purdue was cut. During Phase III, St. Regis tested and made the entire system completely operational.

Integrating Landsat remote-sensing technology into FRIS required St. Regis to spend over $1,300,000 for hardware and to hire two data specialists (one analyst and one programmer). However, the company estimated that these costs would be recovered in approximately 8½ years through: 1) increased efficiency in forest mapping, and 2) considerable improvement in efficiency of field operations. By using Landsat data, the company was able to identify areas where only minor changes in the area or condition of the forest could be better defined, and to assign less field work to them. This decreased the total amount of field-crew time required and enabled more effective use of the field crews in areas where significant changes were occurring.

The utilization of Landsat data in the FRIS was described in detail at a symposium held in Jacksonville in May 1981, to which key personnel from all of the forest industries in the country were invited. As an indication of the widespread interest in the possible use of Landsat data, all except one of the forest industry companies sent representatives (usually senior-level executives) to the symposium. Two different types of users can be defined: the larger forestry companies like St. Regis or Great Northern, who would develop their own capability to analyze and use Landsat data, and the smaller companies who would like to have access to the same type of information, but cannot afford such an operation themselves. The smaller companies would be interested in purchasing value-added services. Companies specializing in analysis of Landsat data as a service to forest industries might have considerable demand for their products.

To date, however, forestry companies other than St. Regis have made little progress in incorporating Landsat data into their information system. Value-added companies have not increased their business with forest companies significantly. The reasons for this may be varied and complex, but two factors predominate:

1. There is no commitment by the U.S. Government or any private group *to supply data* promptly on a continuous basis, and forest industries are not yet ready to modify their entire method of monitoring the resource base.*
2. Potential users of the data are worried about the *cost* of the primary data. As previously indicated, because of the number of decades required to grow a crop of trees to merchantable size and the fact that periodic inventories of the resource base are necessary, the resources that can be allocated to any one inventory are minimal. At $200 per CCT, the cost of the price of digital data was very reasonable, even when the forested areas of interest involved only a small portion of the area covered by that particular frame of Landsat data. However, the announced price of $4,400 per frame of Landsat 4 thematic mapper data (starting February 1985), makes the cost of obtaining the data a major issue for forestry companies, especially when there seems to be no indication that such data costs will stabilize. **If the Landsat system is transferred, cost increases will remain a major concern.**

It seems clear that the forest industries are not about to commit themselves to use a data-collection system such as Landsat unless the long-term implications of such a commitment are clear, and that the cost, availability, and utility of the data can justify such a change in their current methods of obtaining needed information.

The forest industry will not begin to use satellite data on a regular basis until it is assured that they will meet forestry information needs. Unfortunately, many individual studies have shown the benefits and limitations of Landsat data, but most of these have been of a research or a one-time demonstration nature; very few involved industry-defined operational constraints. Therefore, there is still a major need for development, demonstration, and evaluation of the technology under *operational conditions*. For instance, in the St. Regis project, researchers found that wintertime Landsat data were superior to spring or summer data because the primary information need was for stands of coniferous rather than deciduous forest cover.

As the St. Regis project and other studies have shown, Landsat data for forestry purposes have considerable potential. The St. Regis project used geometrically rectified Landsat data overlaid onto a landownership map. Areas of coniferous, deciduous, and other cover types were then identified and these results were compared with existing cover-type maps to locate areas where differences existed between the two data sets. Field crews then concentrated their efforts in these areas of discrepancy. Landsat data from a second date were overlaid onto the first data set, and used to determine the extent of logging and reforestation operations, and whether the field records agreed with the results obtained from the first Landsat data set. Areas in which no significant changes in forest cover occurred were also defined; this led to modifications of the statistical sampling strategy for field inventories.

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*Because of annual cycles of industry operations, the potential for obtaining Landsat data within a reasonable time after it is collected is of concern. The consistency of format is also of concern because of the costs of revising software and hardware whenever changes in the format of the data occur.

Landsat data have been applied to selecting the optimum location for a paper pulpmill in relation to the potential timber supply and transportation network. Such procedures may also prove effective for locating potential sources of wood supply for existing mills and then arranging a mutually beneficial long-term forest management lease with the owner.

In summary, Landsat data have been or could be of benefit in monitoring field records and rapid updating of maps, improved efficiency of field operations, timber supply monitoring, and long-term planning. It must be emphasized, however, that the effective use of Landsat data by forest industries involves developing entirely new information management systems that integrate Landsat data with many other types of data obtained from a variety of sources.

The decision to use Landsat data therefore represents a very major change in the data-collection and information analysis techniques of a corporation. In spite of many potential uses of Landsat data, it is clear that such satellite data will not entirely replace aerial photography because the characteristics and information content of the two data types are quite different, each having unique advantages and significant limitations. The key to effective use of Landsat data involves their appropriate integration with other data. However, unless concerns over continued data availability (in a standardized format that does not change at frequent intervals), and the future cost and timeliness of the data are effectively addressed to the satisfaction of corporation executives, many potential users of Landsat data will continue to use other forms and sources of data for their information systems.

Appendix G

Monitoring Desertification Processes* by Landsat

The Landsat remote-sensing system has proven uniquely effective for measuring and determining changes in the global landscape. It is particularly applicable to monitoring and assessing processes that lead to desertification. About one-third of the Earth's surface is arid or semi-arid and therefore highly vulnerable to a variety of degradation processes. Such stresses, if continued unchecked, may lead to ecological impoverishment and, ultimately, to desert-like conditions.

Most commonly, desertification is triggered or intensified by periods of drought, and exacerbated by poor land-use practices such as rapid land clearing for agriculture or fuel. As food production becomes more important, large land areas run the risk of becoming less and less productive as a result of losing forest. Until recently, attempts to quantify and map the locations of desertification were based on fragmentary and highly local data subject to differing interpretation. Land remote sensing from space could provide the necessary information to monitor desertification.

The Conference on Desertification, held in Nairobi, Kenya, in 1977, recognized the need for developing a means for systematic land assessment.[1] Agencies of the U.S. Government, especially the Agency for International Development and the National Aeronautics and Space Administration, have since experimented with using the Landsat system as a primary land survey tool to monitor desertification.

The global dimensions of desertification are not precisely known but, by any account, are grave indeed. Each year, as many as 14 million acres of previously productive land become barren. Acreage lost to production represents a substantial economic loss to the global economy. One study[2] estimates $7 billion in losses from loss of range and pastureland and $9 billion in lost agricultural production each year. Financial losses in industrialized countries are paralleled by adverse human and social consequences in arid lands of the less developed world.

With the advent of satellite multispectral scanners (MSS) it has become possible to sweep Earth's surface repetitively, depict the scene in pixels about 1 acre across, determine surface reflectance characteristics in multiple bandwidths, and process these data rapidly by computer for interpretation and presentation. Based on this capability, desertification specialists, meeting under the international auspices of the U.N. Food and Agriculture Organization (FAO) and the U.N. Environmental Program (UNEP), have concluded that land condition should be expressed in gradation of geographical units.[3] The objective is to enable land comparisons on the basis of vegetation complexes, ecosystems, soil associations, and other qualities amenable to identification by remote sensing. They have created models which permit Landsat data to be combined with meteorological and other data to determine general conditions over relatively vast and sometimes remote areas. Use of this new technology presently offers the only economically feasible method for obtaining synoptic information over wide areas, which is essential to understanding and controlling desertification.

The special properties of the Landsat system which permit development of a global data base and the means for accomplishing resource inventory and continuing monitoring are summarized as follows:

- perspective over a range of selected scales,
- combination of spectral bands for categorization and identification,
- repetitive coverage under comparable viewing conditions,
- direct measurement based on one set of reflectance conditions for a wide area,
- signals suitable for digital storage and subsequent manipulation, and
- accessibility over remote and difficult terrain and across political divisions.

With the establishment of baseline conditions it is possible to monitor the severity, rate, and trends based on standard sets of indicators (see table G-1).[4] The absence of this type of information in the early 1970's contributed to the failure to institute relief measures in the drought-stricken Sahel region of West Africa

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*Desertification is the sustained decline and destruction of the biological productivity of drylands owing to stress caused by humans, sometimes in conjunction with extreme weather or drought.

[1] U.N. Conference on Desertification, September 1977, Roundup, Plan of Action and Resolutions, New York, 1978.

[2] Desertification papers prepared for the Nairobi Seminar on Desertification, Priscilla Reining (ed.), American Association for the Advancement of Science, Washington, D.C., 1978.

[3] U.N. Food and Agriculture Organization and U.N. Environmental Program (FAO-UNEP) Expert Meeting on Methodology for Desertification Assessment and Mapping, Geneva, May 1979.

[4] Handbook on Desertification Indicators, compiled by Priscilla Reining (ed.), American Association for the Advancement of Science, Washington, D.C. 1978.

Table G-1.—Implementation of Desertification Indicators With Remote Sensing

Detailed	Reconnaissance	Synoptic		Repetition Rate
Soil:				
1. Mosaic coloring	+	+	−	
2. Surface seals	−	+	+	
3. Major dust storms	+	+	+	daily
4. Sand drift, dunes	+	+	−	annual or longer
5. Remobilized dunes	+	+	+	annual
6. Obliteration of field patterns	−	+	+	annual
7. Salt crust	+	+	−	annual
Water:				
1. Falling water tables or increasing saline ground water (depth or stress on phreatophyte)	+	+	−	annual
2. Abandonment of irrigated lands based on ground water	+	+	+	annual
3. Waterlogging moist ground	+	+	−	annual
4. Abandoned land in irrigated systems	+	+	+	annual
5. Surface water changes in extent and duration	+	+	+	half monthly
6. Silting	+	+	+	annual
7. Turbidity	+	+	+	half monthly, event related
8. Extension of gully sytems	+	+	+	5 years
9. Regional changes in seasonal limits on rainfall (climate and water balance)	−	−	+	half monthly, daily over long period
Vegetation:				
1. Changes in cover or perennial vegetation	+	+	+	dry season, 5 years
2. Changes in distribution	+	+	−	dry season, 5 years
3. Annual vegetation (crops)	+	+	+	half monthly
4. Denuded areas	+	+	+	half monthly
5. Biomass of crops	+	+	+	seasonal
Animals:				
1. Key species, populations, herd composition (larger animals)	+	−	−	annual
Land use:				
1. Changes in irrigation	+	+	+	annual or longer
2. Changes in dryland area	+	+	+	annual or longer
3. Proportion of fallow to cropland	+	+	+	annual
4. Stressed rangeland areas	+	+	+	annual
5. Devegetation of mined areas	+	+	+	5 years
6. Ground disturbance around mines	+	+	−	annual
7. Mine waste disposal	+	+	−	5 years
8. Deforestation around settlements	+	+	+	annual
9. Deforestation in relation to sand drift	+	+	+	annual
10. Tourism and recreation (ground disturbance)	+	+	−	annual
11. Change in settlements (new settlements, expansion of existing settlements, and abandonment of settlements)	+	+ (may or may not be seen)	(+)	annual

Key: +can be used.
−cannot be used.

Notes:
Detailed = scale 1:10,000, low-level aircraft.
Reconnaissance = scale between 1:20,000 and 1:100,000 (Landsat-TM or SPOT-MLA).
Synoptic = scale 1:250,000, satellite (Landsat-MSS).

SOURCE: UNEP, Report of Expert Meeting on Methodology for Desertification Assessment and Mapping.

until after thousands had died of starvation and many more had been forced to migrate, a condition that led to enormous social and political instability in the area.

With U.S. help, several international organizations are attempting to monitor and understand desertification.[5] A Global Environmental Monitoring System (GEMS) is being coordinated under the U.N. Earthwatch Program. FAO has under construction a Global Information and Early Warning System aimed at mitigating the effects of famine around the world. These systems will not become fully operational until civilian satellite remote sensing attains greater maturity. Land and meteorological satellites and a full panoply of aerial and ground observations will eventually be required to carry out the objectives of these ambitious but feasible programs.

The World Weather Watch (WWW) provides an important input to monitoring desertification through the Global Observing System (GOS). WWW is a collaborative effort by which 145 member nations pool meteorological capabilities and the data from 8,500 synoptic stations and other sources. GOS acquires data from both polar-orbiting and geostationary satellites.

In the United States, desertification is a major land problem for substantial portions of 17 Western States. The United States and Mexico have made the combatting of desertification in their common arid ecoregions a major continuing item of technical cooperation, and have placed particular emphasis on common use of Landsat imagery. The Department of State has been responsible for organizing periodic joint meetings of experts, and has directed U.S. contributions to monitoring activities.

Within the United States, a number of agencies and institutions are active in studying, assessing, and monitoring desertification processes. Those most prominent are:

- U.S. Department of Agriculture
  - —Soil Conservation Service
  - —National Forest Service
- Department of the Interior
  - —Bureau of Land Management (BLM)
  - —Bureau of Indian Affairs
  - —U.S. Geological Survey
  - —Office of Surface Mining
- Department of Commerce
  - —Climate Change Assessment
  - —National Weather Service
  - —National Environmental Satellite System

In April 1982, a comprehensive interagency study published by BLM reported the status of desertification in the United States.[6] It emphasized monitoring needs and statutes mandating land condition-monitoring projects including:

1. the Soil and Water Resources Conservation Act of 1977 (RCA), Public Law 95-192;
2. the Forest and Rangeland Renewable Resources Planning Act of 1974 (RFP); and
3. the Federal Land Policy and Management Act of 1976 (FLPMA).

Collectively, the RCA, RPA, and FLPMA direct in very specific terms the preparation and maintenance of continuous resource inventories by the Federal agencies. Congress has further recognized the importance of effective coordination of the collection and analysis of natural resources information. One active vehicle for accomplishing this was provided by the Interagency Agreement Related to Classifications and Inventories of Natural Resources, which was signed by five leading land agencies in 1978. It has produced several standard manuals. The product of a single national land satellite system has helped pull together resource specialists who are addressing different tasks using the same basic data.

BLM, custodian of 427 million acres of public land, provides one specific example of response to monitoring requirements. BLM joined with the U.S. Geological Survey in modeling and categorizing Landsat digital data for purposes of mapping and describing wildland vegetation for a large section of the arid southwest. Strict cost records were kept, and the task was accomplished at a favorable rate of $0.07 per acre, including labor, computer time, and cost of tapes.

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[5] International Symposium on Remote Sensing of Environment, Conference on Remote Sensing of Arid and Semi-Arid Lands, November 1981, Cairo, Egypt.

[6] U.S. Department of the Interior, Bureau of Land Management, "Desertification in the U.S.: Status and Issues," Washington, D.C., April 1982.

Appendix H

El Nino and Climatic Variations

Periodically, the failure of the Eastern Trade Winds to develop in the eastern equatorial Pacific causes abnormal weather and climate, especially in Peru, as the Peruvian Current, an upwelling nutrient-rich system, gives way to a warm easterly flowing current. This extreme condition is called El Nino. Because of its strength and widespread effects on global weather patterns, the El Nino of 1982-83 has been labeled by some as the most remarkable climatic event of the century.[1] [2] [3] Satellite-derived sea-surface temperatures will eventually allow scientists to monitor the development and extent of the change and lead to better understanding, and hence predictions, of El Nino conditions. New techniques of measuring sea-surface temperature from the National Oceanic and Atmospheric Administrations (NOAA) satellite sensors were inaugurated in November 1981 by the National Environmental Satellite Data and Information Service (NESDIS). The 1982-83 El Nino began to develop over the central equatorial Pacific during June and July 1982, but it did not reach the South American coast until September 1982.

Several excellent NOAA-7 images have enabled delineation of surface thermal patterns off the South American coast (figs. 5 and 6 in ch. 5). These temperature patterns agree with buoy temperatures and permit an integrated picture of this climatic anomaly. With extensive monitoring by satellites, bouys and ships, this, the most significant El Nino of modern times, has been documented, studied, and understood better than any other El Nino.

The 1982-83 El Nino has temporarily destroyed the lush fishing industry of Peru, thereby harming the economy of that nation. It also produced torrential rains in desert areas, triggering mudslides and floods; devastated the adobe housing of most of the rural inhabitants; and generally disrupted transportation. Abnormal rains related to El Nino patterns have also plagued Central America and California. The circulation patterns producing this El Nino have extended all around the world.

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[1] M. A. Cane, "Oceanographic Events During El Nino," *Science* 222, 1983, pp. 1189-1194.

[2] E. M. Rasmusson and J. M. Wallace, "Meteorological Aspects of the El Nino/Southern Oscillation," *Science* 222, 1983, pp. 1195-1202.

[3] R. T. Barber and F. P. Chavez, "Biological Consequences of El Nino," *Science* 222, 1983, pp. 1203-1210.

Appendix I

Monitoring Volcanic Activity

Until the catastrophic eruption of Mount St. Helens in Washington State on May 18, 1980, most Americans regarded volcanoes as curious geologic features that affected *other* countries. The eruptions of Mount St. Helens have renewed public interest in this spectacular form of geologic catastrophe.

Within minutes after the initial blast from Mount St. Helens the geostationary meteorological satellite (GOES) began recording this awesome event at half-hourly intervals from 22,000 miles above the Equator (fig. I-1). A vast plume of ash and smoke rose into the atmosphere and was carried by the winds for hundreds, even thousands of miles. Each half hour the progress of the dust veil was recorded by GOES, allowing meteorologists to advise those downwind what to expect in terms of ash fallout and when it might arrive. Aircraft were rerouted. In fallout areas, local governments issued advisories. The magnitude of the blast alerted hydrologists that rivers could change course, lakes could drain, and floods were both probable and imminent.

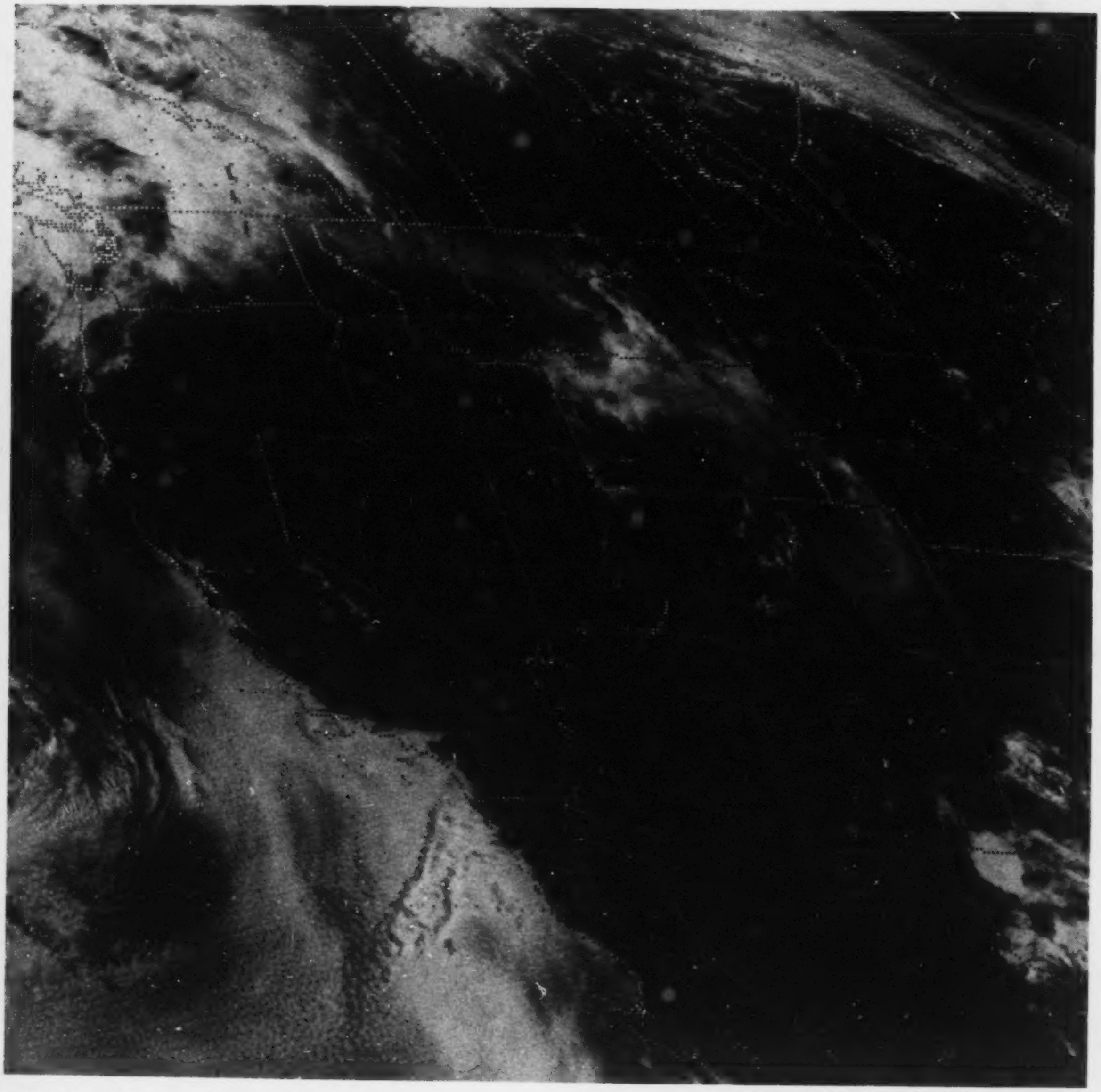
Other volcanic eruptions that have been studied by satellites include the Krafla, Iceland, eruption of February 1981; the Heckla, Iceland, eruption of April 1982; the Alaid, U.S.S.R., eruption of 1981; the Galunggung, Indonesia, eruption of July 1982 (fig. I-2); and the El Chichon, Mexico, eruption of April 1982.

The Icelandic eruptions tended to be in the form of large lava flows, and were best detected by the thermal infrared channels on the National Oceanic and Atmospheric Administration's (NOAA) polar orbiter. The Alaid eruption sent a plume of ash across the North Pacific for hundreds of kilometers. El Chichon sent a plume of sulfur dioxide and hydrogen sulfide gas high up into the stratosphere, where it girdled the globe in about 28 days, then spread slowly over all the Northern Hemisphere in the form of sulfuric acid droplets. This highly unusual eruption is being monitored carefully all over the world because of its potential for temporarily altering the climate of the Northern Hemisphere. The stratospheric migration of this atmospheric "cloud" was ingeniously tracked by NOAA scientists by noting artificial temperature anomalies in sea-surface temperatures caused by the attenuation of solar energy by the sulfuric acid aerosols.

Galunggung in southwestern Java has erupted in fits and starts for years, but it made headlines when its plume was penetrated by a British passenger airliner which nearly crashed when hot volcanic dust clogged its jet engines. Incredibly, the same airliner 6 months later again was victimized by a Galunggung eruption and again was nearly incapacitated by volcanic dust.

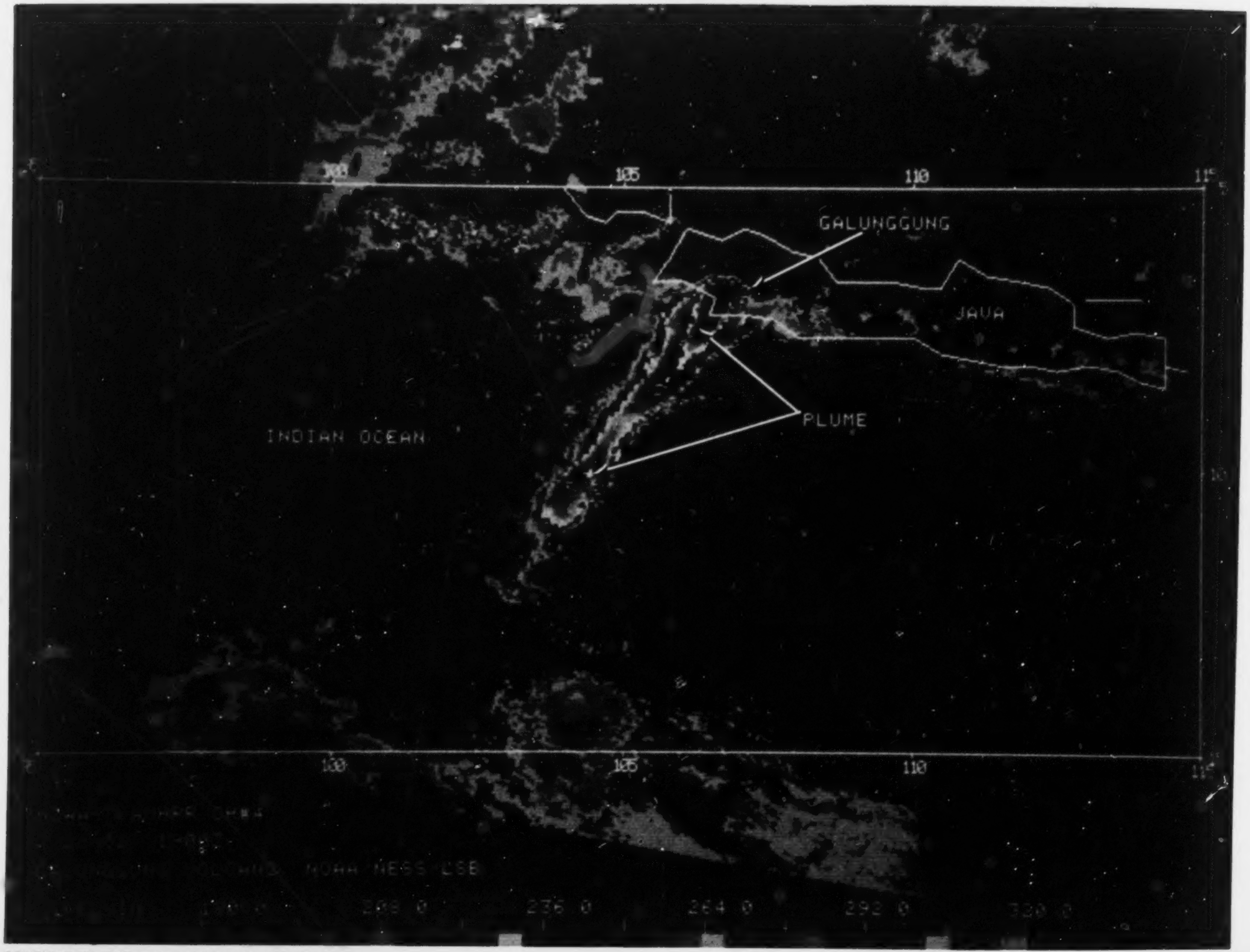
Aviation authorities are seriously considering a monitoring scheme using the World Meteorological Organization's World Weather Watch satellites to put out aviation alerts on possible volcanic eruptions based on satellite imagery.

Figure I-1.—May 18, 1980, Eruption of Mount St. Helens, Wash., as Recorded by the GOES Satellite, 0845PDT



SOURCE: National Oceanic and Atmospheric Administration.

Figure I-2.—Computer-Enhanced, Enlarged False-Color Image of Galunggung Volcano, Java, Showing the Plume Extent at 1900Z, 7/28/82. A BOAC Aircraft Lost All Four Jet Engines As It Encountered This Plume


100
105
110
115
GALUNGGUNG
JAVA
PLUME
INDIAN OCEAN
100
105
110
115
NOAA NESS CSB
208 0
236 0
264 0
292 0
320 0

SOURCE: National Oceanic and Atmospheric Administration.

Office of Technology Assessment

The Office of Technology Assessment (OTA) was created in 1972 as an analytical arm of Congress. OTA's basic function is to help legislative policymakers anticipate and plan for the consequences of technological changes and to examine the many ways, expected and unexpected, in which technology affects people's lives. The assessment of technology calls for exploration of the physical, biological, economic, social, and political impacts that can result from applications of scientific knowledge. OTA provides Congress with independent and timely information about the potential effects—both beneficial and harmful—of technological applications.

Requests for studies are made by chairmen of standing committees of the House of Representatives or Senate; by the Technology Assessment Board, the governing body of OTA; or by the Director of OTA in consultation with the Board.

The Technology Assessment Board is composed of six members of the House, six members of the Senate, and the OTA Director, who is a nonvoting member.

OTA has studies under way in nine program areas: energy and materials; industry, technology, and employment; international security and commerce; biological applications; food and renewable resources; health; communication and information technologies; oceans and environment; and science, transportation, and innovation.

OTA-TM-ISC-20